GPO PRICE $ ______

CFSTI PRICE(S) $ ______

Hard copy (HC) 3.00

Microfiche (MF) .65

ff 653 July 65

FINAL REPORT
FOR
WIDEBAND TELEVISION RECORDER

FACILITY FORM 602

N68-19047 (ACCESSION NUMBER)

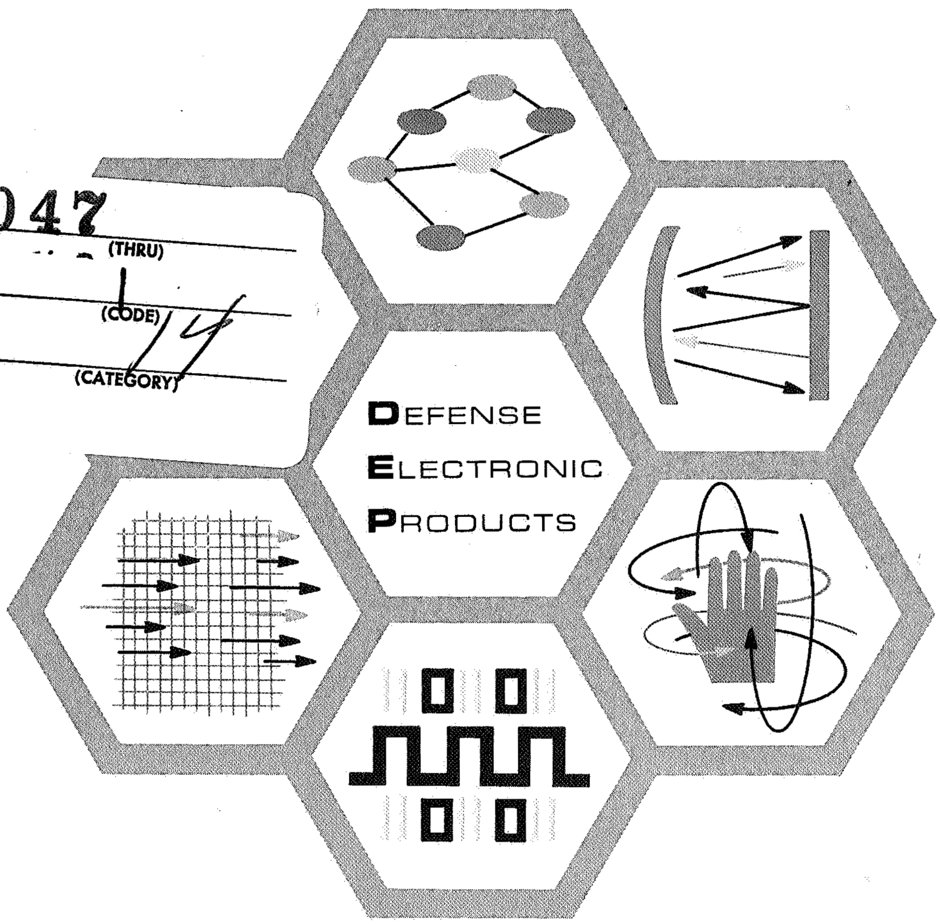
94 (PAGES)

CR-93526 (NASA CR OR TMX OR AD NUMBER)

1 (THRU)

(CODE)

14 (CATEGORY)



PREPARED FOR

NASA MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

RCA RADIO CORPORATION OF AMERICA ■ DEFENSE ELECTRONIC PRODUCTS

FINAL REPORT

FOR

WIDEBAND TELEVISION RECORDER

CONTRACT NAS 9-4629

PREPARED FOR

NASA MANNED SPACECRAFT CENTER

HOUSTON, TEXAS

PREPARED BY

RADIO CORPORATION OF AMERICA

COMMUNICATIONS SYSTEMS DIVISION

CAMDEN, NEW JERSEY

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SUMMARY

This document forms the final report for the effort performed by the Radio Corporation of America on NASA Contract NAS 9-4629. The object of the program was to develop a variable bandwidth, miniature, television recorder/reproducer with an upper bandwidth of 4 MHz. This development was proposed to be accomplished through combination of integrated circuit electronics, a Negator-spring reeling system and a miniature helical scan recording station. It was accomplished accordingly, and the delivered equipment demonstrated the characteristics listed in Section 1.1, Salient Features.

Since complete instruction manuals were delivered with the equipment, this document centers largely on tests and results obtained during the development and during pre-acceptance tests, elaborates on design modifications, and sets forth recommendations and conclusions based on the results obtained.

WIDEBAND TELEVISION RECORDER/REPRODUCER

1.0 INTRODUCTION

RCA's Wideband Television Recorder/Reproducer combines three elements which contribute most significantly to the low power consumption, small size, and high reliability of the unit. These elements encompass 1) the electronics, which employ integrated circuits to the maximum extent consistent with good design, 2) the negator spring reeling system, which has been proven as a reliable, power-saving system in RCA's Tiros, Nimbus, and Gemini Recorders, and 3) the ultra-miniature, helical scan, recording station which affords inherently precise time stability.

This last element, the helical scan recording station, is the key to the recording system. This device forms a helical path for the tape around a high speed rotating headwheel. The helical path causes the tape to be scanned by the headwheel diagonally from edge to edge. The recorded tape format resulting from this action consists of a series of 0.005 inch wide tracks at an angle of 45° with respect to the tape edges. The 45° angle of the helically recorded tracks is established by the specific geometry of the recorder elements. In this recorder the tape is wrapped approximately 190 degrees around the wheel and continuous recording is effected through two diametrically opposed recording heads in the high speed rotating headwheel. The specific scanning and tape speeds for the recorder are listed below with other salient features of the recording system.

1.1 SALIENT FEATURES

- Size	10 x 14 x 6.1 inches
- Weight	30 lbs.
- Bandwidth	DC to 4MHz DC to 0.5MHz
- Record Time	1/2 hr. @ 4MHz 4 hrs. @ 0.5MHz
- Head-to-Tape Speed	1120 in/sec @ 4MHz 140 in/sec @ 0.5MHz
- Tape Speed	10 in/sec @ 4MHz 1.25 in/sec @ 0.5MHz

- Rewind Time	less than 8 minutes
- Signal-to-Noise Ratio (peak-to-peak to rms)	38 db
- Input/Output Levels	1.0 volts composite into 50 ohms 2.0 volts composite into 100 ohms
- Input Power	+28 ±4 Vdc
- Power Dissipation	55 watts @ 4MHz 45 watts @ 0.5MHz
- Time Stability	Within FCC Standards, Section 3.3687(a), para. 7

1.2 THE RECORDING SYSTEM

The Wideband Television Recorder/Reproducer consists of three major sub-systems; the tape transport, the motor drives and controls, and the video electronics.

1.2.1 Tape Transport

The tape transport, which is illustrated in Figure 1-1, includes the tape reeling system, the tape (or capstan) drive system, the helical scanning assembly, the erase head, the longitudinal record/reproduce heads, and an assortment of tape guides.

1.2.1.1 Reeling System

The tape reeling system employed is the negator spring system which has proven so successful in RCA's line of narrowband spacecraft recorders. The specific advantages of this reeling technique in the wideband recording system are the low power consumption and the uniform and repeatable tension which contributes significantly to the time stability of the unit. The influence of this parameter is discussed in detail in paragraph 1.2.1.3.

1.2.1.2 Tape Drive System

The primary power element in the tape or capstan drive is a hysteresis synchronous motor. Since three different tape speeds are required in the system, two different pole

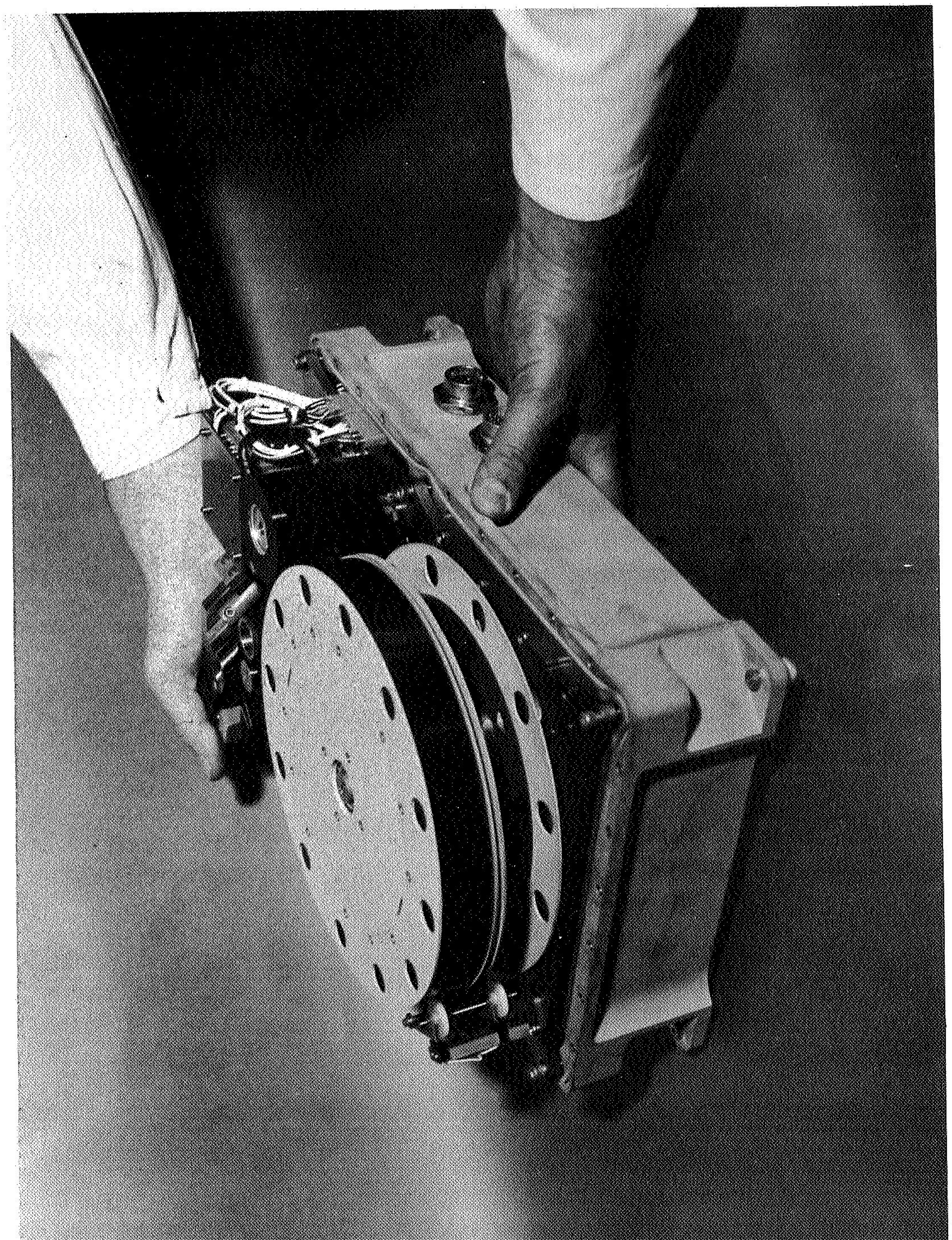


Figure 1-1. Wideband Television Recorder

configurations are employed and are contained in the same motor assembly. A two pole configuration is employed for high speed record and playback and for rewind. In the high speed record and playback mode the two pole motor is driven from a 2 Ø, 100 Hz square wave source. In rewind, the two pole motor is driven from a 2 Ø, 400 source. The four to one difference in drive frequency, of course, yields the four to one speed-up during rewind. The motor configuration for low speed record and playback is a 16 pole motor which is driven from a 2 Ø, 100 Hz square wave source. The 100 Hz drives mentioned above are controlled by an internal timing standard during record, but during playback the nominal 100 Hz is derived from a Voltage Controlled Oscillator in the Capstan Servo so that the nominal 100 Hz is, in practice, frequency modulated to accommodate alignment of the video heads with the recorded tracks. This servo is discussed further in paragraph 1.3

The common motor shaft is coupled to the capstan output shaft through a two stage, mylar belt/pulley reduction. This mylar belt/pulley transmission system is again a technique which has been proven in RCA's narrowband spacecraft recorders and is employed in this system for its superior low flutter properties. The output member of the capstan drive is a urethane coated shaft which forms a closed-loop drive around the helical scanning station. The closed loop drive results from the fact that tape is metered into and away from the helical scanning station. The advantage of this type of drive is that it acts as a low pass filter on tension variations which occur external to the closed loop. This filtering action, of course, provides further immunity from the effect of tension variations on time base stability. The influence of tension on time base stability is discussed in more detail in the following section.

1.2.1.3 The Helical Scanning Station

The helical scanning station incorporates a high speed rotating headwheel which develops the high head-to-tape speed necessary for wideband recording. The scanning station also causes the tape to be brought into contact with the headwheel for about 190° of the wheel rotation. Continuous recording is accomplished by employing two diametrically-opposed recording heads in the wheel. With this configuration, at least one head is always in contact with the tape. The recorded tracks are diagonally arranged on the tape at an angle nearly equal to the helix angle. Spacing between consecutively recorded tracks, of course, is established and controlled by the tape motion.

Two facets of the scanning station design establish, to a large degree, the level of time base accuracy which can be attained in the recorder. The most critical of these two facets is the immunity of the station to time base distortion due to tape length changes. This dependence on tape length changes is peculiar to rotary head recorders and stems from the fact that the information is recorded on a series of disjointed tracks. To obtain an accurate recombination of the disjointed information during playback, the length of the tracks during playback must accurately duplicate the length which existed during record. If this condition is not met, a sharp discontinuity in the phase of the playback signal will occur at the instant the playback signals from the two heads are recombined.

Three design features of the recorder combine to minimize this source of time base distortion. Two of the features, the reeling system and the closed loop tape drive, maintain accurate tape length through inherently smooth tape tensioning. The other feature minimizes the time base discontinuity simply by minimizing the absolute changes in tape length which can occur during the interval between the recombining switches. This is directly accomplished through the extremely small headwheel diameter which minimizes the length of the disjointed tracks.

The second facet of the scanning station design which significantly influence time base accuracy is the speed constancy of the headwheel. In the present design the headwheel is driven by a hysteresis synchronous motor through a mylar belt/pulley reduction. This motor, like the capstan motor, employs different pole configurations to provide the two different head-to-tape speeds.

In all modes of operation the motor is driven from an accurate frequency source which provides a speed accuracy well beyond that required for standard television rates.

1.3 MOTOR DRIVES AND CONTROLS

The primary frequency standard in the recorder is a 3200 Hz tuning fork. This standard is counted down to develop the 2 Ø, 100 Hz and 2 Ø, 400 Hz references which control the motor drivers in most operating modes. The motor drivers are basically switching circuits which convert the input dc to the 2 Ø, square wave drives required by the motors. This conversion of power is normally controlled by the 2 Ø references derived from the 3200 Hz tuning fork. The one exception to this practice centers on the operating mode of the capstan during playback. In this mode the capstan is servoed to accommodate the alignment of the video heads with the recorded tracks.

The operation of this servo depends on a recorded clock track. In the record mode, a once-around pulse is derived from a tonewheel which is fixed to the headwheel shaft. This pulse is recorded on a longitudinal track (control track) on one edge of the tape. This provides a reference of the relative headwheel and tape positions that existed during record. During playback the longitudinally recorded pulse is reproduced and compared in phase with the tonewheel signal. This comparison indicates the relative headwheel and tape positions that exist during playback. The comparison thus serves as the basic error signal for the capstan servo. Corrections for phase errors between the two signals are accomplished by applying the error signal to a voltage controlled oscillator. This VCO replaces the 1600 Hz reference in the 2 Ø, capstan motor, drive reference. Hence, as the error signal modulates the output frequency of the VCO, the drive frequency to the motor is changed proportionately. The motor remains synchronous with the drive frequency and hence speeds up or slows down until the proper tracking is obtained.

1.4 VIDEO ELECTRONICS

The video electronics employed in the present system are functionally equivalent to those used in broadcast television recorders. Referring to the Block Diagram in Figure 1-2, the incoming video signal is encoded on an fm carrier which has an undeviated frequency of about 4.8 MHz for the 4 MHz bandwidth and about 600 kHz for the 0.5 MHz bandwidth. The full amplitude video signal deviates this carrier to approximately 7.2 MHz and 900 kHz, respectively. The FM signal is applied to record amplifiers which, in turn, drive the two video heads. The coupling of the signals into and out of the heads is performed by a rotary transformer with a 1:1 turns ratio.

During playback the two head output signals are processed initially as two independent channels. Each output signal is applied to a preamplifier which is located adjacent to the rotary transformer. The signal is further amplified in the Playback Amplifiers and equalization is applied to restore the sideband energy to a more linear form than is received directly from the tape. At this point the signals are recombined into a single FM channel through a 2 x 1 switch. This signal next receives 40 db of hard limiting which provides immunity to noise and amplitude fluctuations. The limited fm signal is next applied to the FM Demodulator which reproduces the original video signal. The final processing performed on the signal consists of additional amplification and impedance matching.

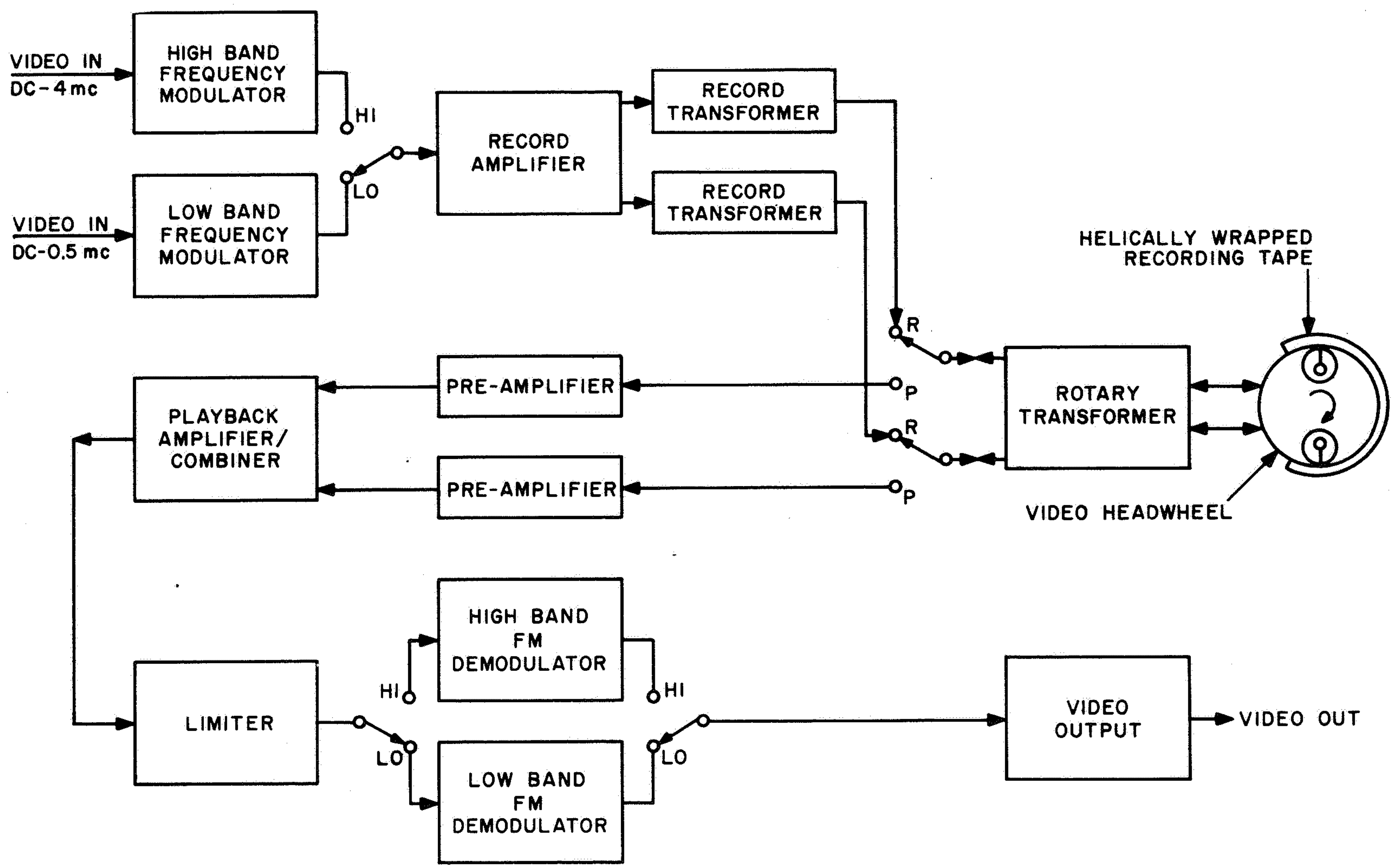


Figure 1-2. Block Diagram, Wideband Television Recorder

2.0 MECHANICAL CONSIDERATIONS

2.1 TAPE TRANSPORT

The purpose of the tape transport is to provide for tape storage and for controlled motion of the magnetic tape and video heads. In addition to serving these purposes, the Wideband Television Recorder transport had to be highly reliable and low in power consumption, volume, and weight. These inter-related constraints were best met with a system utilizing a doubly wrapped single capstan, negator torqued coaxial reeling system, and a helical scan record/reproduce head assembly.

2.1.1 Tape Reeling System

To minimize power consumption and weight, a negator reeling system similar to that used on RCA's TIROS, Gemini and Nimbus recorders was employed. The main advantage of this system is that no reel motors are required. The capstan drives the take-up reel through a constant-torque spring coupling.

The reel assembly consists of two magnesium alloy coaxial reels, two negator spring assemblies, and a planetary gear arrangement. Approximately 1600 feet of recording tape exchanged between reels provides the thirty minute and 4 hour recording times required at the 4 MHz and 0.5 MHz bandwidths.

The diameter ratio of full reel to empty reel was kept to a minimum (8.7 inch to 6.7 inch) to maintain a small tape tension differential due to varying moment arm. This minimizes the change in capstan motor torque requirement.

The advantage of this design is that repeatable record/playback tape tension is achieved without reel motors, tension servo, and other associated electronics.

The reeling system was designed to accommodate four negator springs but early systems tests demonstrated that the tension developed by only two of the springs was adequate for good head-to-tape contact. The two springs and reels are coupled through a planetary gear ratio of 1.45 : 1 for good head-to-tape contact. This provides a repeatable record/playback supply tension of 5.90 oz. at start-of-tape, 6.27 oz. at mid-tape, and 7.68 oz. at end-of-tape.

2.1.2 Tape Drive

A doubly wrapped urethane coated capstan is used to drive the tape. A tape wrap of approximately 210 degrees around the capstan allows for frictional drive without pinch belts or rollers.

A closed loop results from the fact that tape is metered into and away from the helical scanning station. The advantage of this drive technique is that it acts as a low pass filter to tension disturbances from outside the loop. This filtering action provides further immunity from the effect of tension variations on time base stability.

The capstan is driven by a hysteresis synchronous motor through a two stage, mylar belt/pulley reduction. This transmission system has been proven in RCA's spacecraft recorders and was employed for its superior low flutter properties.

Tape speeds of 10 ips and 1.25 ips provide for the high and low bandwidth requirements, respectively, and a speed of 40 ips accommodates rewind.

2.1.3 Video Scan Assembly

The helical scan principle was used instead of transverse scan mainly because of geometrical considerations leading to a low volume system. It has the advantage that it can be used with the coaxial reel, single capstan configuration which causes a significant reduction in transport volume.

Another advantage offered by helical scan is that the tape can be wrapped completely around the periphery of the headwheel whereas the transverse scan is limited to a wrap of less than 180 degrees. This causes a reduction in the number of heads required, and hence, a reduction in electronics.

A disadvantage of helical scan is that time base stability is influenced by the longitudinal tape speed and the tape tension. These effects were minimized by utilizing a short scan length and sophisticated servo techniques.

Short scan length (1.26 inch) was incorporated by establishing the headwheel diameter as small as practicable (.7404 inch). A tape wrap of 190 degrees around the headwheel allows continuous recording with two diametrically opposed record/playback heads. A helix angle of 45 degrees and the longitudinal tape speeds were established by the necessary head-to-tape speed and the specific geometry of the recorder elements.

The helix proper was fabricated from K-Monel for toughness, and ground to a #16 finish to minimize the tendencies for vacuum buildup between the helix and tape. The anti-helices which lead into and out of the video scan assembly were steel blasted to minimize this tendency. Before these measures were taken, the helix and anti-helices tended to polish and induce a stick-slip disturbance to the tape.

The video scan assembly incorporates a single slotted tonewheel and two permanent magnet pick-ups spaced at 180 degrees. Each tonewheel pick-up generates one pulse for each once-around of the video headwheel. The tonewheel slot is oriented such that the pulses occur during the head overlap period. The pulses are utilized to generate a clocking signal during record and capstan servo reference and gating signals for combining video head outputs during playback.

2.1.4 Tape Rollers

In the development of the tape rollers, fixed flange and rotating flange rollers were tested and evaluated. It was determined that fixed flange rollers were superior; the rotating flange rollers introduced disturbances to the edge of the tape. This was caused by the uneven, yet parallel, nature of the available magnetic tape.

Also, both crowned and uncrowned rollers were tested. Crowned rollers achieved the best guiding characteristics. A crown of .004 inch (on the diameter) provided accurate tape guidance.

2.1.5 Motors

Three sets of motors were evaluated for use during the course of the development program. All were hysteresis synchronous motors with speed-torque characteristics nearly equivalent to salient pole machinery (stall torque less than pull-in torque). Motors with this characteristic were selected for their combined efficiency and simplicity and were arranged with center tapped windings to accommodate starting.

The initial capstan motor was designed for two speed operation with synchronous speeds of 6000 and 750 rpm. The specified speeds were to be developed from a 2Ø, 100 Hz driving source and both windings were to exhibit a minimum pull-out torque of 0.5 oz.-in. with a 48 Vpp square wave drive. This motor successfully operated the breadboard transport but developed only 0.4 oz.-in. of torque at 6000 rpm.

The second capstan motor had a similar 2 pole, 16 pole configuration but had an additional winding on the 2 pole section for operation from a 2Ø, 400 Hz square wave source. This high speed winding was provided for tape rewind and was specified to develop 0.5 oz.-in. at 24,000 rpm. As received, the motor operated the transport reliably in all modes but rewind, which it successfully performed only about 90% of the time. The problem with rewind was attributable to a marginal torque capability of .32 oz.-in. at 24,000 rpm. At 750 and 6000 rpm, this motor developed the specified torques.

The final capstan motor was similar in design to the second unit but the lamination construction was refined to yield the specified torque in all operating modes. This unit performed reliably in the transport and was delivered with the equipment.

The initial design of the headwheel motor was similar to the capstan in that it incorporated 2 pole and 16 pole windings. This unit, however, was planned for operation from a 2Ø, 400 Hz source to give synchronous speeds of 24,000 and 3000 rpm. Two different torque configurations were ordered initially because the exact torque requirement for the headwheel drive was unknown. The torques specified were 0.4 oz.-in. and 0.8 oz.-in. The initial motor received was the low torque version. This unit exceeded the specified torque at 3000 rpm, but developed only 0.35 oz.-in. at 24,000 rpm. When the unit was tested in the breadboard transport, it successfully operated at low speed, but never performed under load at high speed.

The second and third headwheel motors were high torque configurations. In the course of development of this motor, the vendor experienced considerable difficulty in obtaining the specified torque within the size limitation. As a result, the pole configurations were modified from the 2 and 16 to 2 and 4. The desired synchronous speeds of 24,000 and 3000 were obtained by driving the 2 pole winding with 400 Hz and the 4 pole winding with 100 Hz. The initial motor received in this configuration performed within specification at 3000 rpm, but developed only 0.7 oz.-in. at 24,000 rpm. When this motor was tested in the transport, it successfully operated at low speed, but would not successfully attain synchronism at 24,000 rpm. Torque tests run at this time demonstrated that the pull-out torque of 0.7 oz.-in. was attained only when the motor was accelerated without load. Under the operating inertial load the motor pull-out torque was only 0.38 oz.-in. To circumvent this effect, a brushless clutch similar to that employed Gemini was fabricated, but a more desirable solution was obtained before the clutch approach could be fully evaluated. This second approach was the arrangement finally incorporated in the recorder and consisted of accelerating the motor through a ramp-controlled frequency drive. This arrangement insured an optimum magnetization of the rotor and yielded a pull-out torque without load of slightly over 1 oz.-in.

The final motor delivered was identical in concept to the second headwheel motor but was slightly longer and about 20% more efficient. Both of these motors successfully operated the transport, but the final motor, of course had a greater margin of safety.

Once the ramp motor-start circuit had been incorporated for the acceleration of the high speed headwheel motor, it was obvious that the same circuitry could be advantageously employed for acceleration of the high speed capstan motor during rewind. This arrangement was thus implemented and provided an additional margin of safety during rewind.

In the final configuration, the motors and drivers perform in accordance with Table 2-1. Listed power levels are steady-state dc consumption at the input to the motor drivers at 28 Vdc.

Several conclusions can be derived from the table above; first it is obvious that the 16 pole configuration of the capstan motor is relatively inefficient. Since this motor

TABLE 2-1. MOTOR OPERATING CHARACTERISTICS

Motor	Record or Playback		Rewind
	Low	High	
Headwheel	2ø, 100 Hz; 4 pole; 3000 rpm; 4 watts	2ø, 400 Hz; 2 pole; 24,000 rpm; 21.5 watts	2ø, 100 Hz; 4 pole, 3000 rpm; 4 watts
Capstan	2ø, 100 Hz; 16 pole; 750 rpm; 6 watts	2ø, 100 Hz; 2 pole; 6000 rpm; 7 watts	2ø, 400 Hz; 2 pole; 24,000 rpm; 15.4 watts

develops approximately the same torque as the low speed headwheel at one-fourth the speed, it should consume about one-fourth the power (one watt). This inefficiency is typical of multipole, fractional horsepower units, however, and is probably a reasonable trade-off for the simplicity it allows in the total capstan drive system.

A second general observation of interest is the power consumption of the motors in the various modes with respect to the total power used by the recorder.

Typically, the recorder consumes an average of 43 watts in the low speed modes and 53 watts in the high speed modes. Of the 53 watts in the high speed modes, 28.5 watts are consumed by the motors leaving 24.5 watts for electronics and controls. In the low speed modes only 10 watts are consumed by the motors, leaving 33 watts for electronics and controls. Since the consumption by the electronics is, if anything, less in the low speed modes, the additional controls which are powered to switch from high to low consume about 10 watts - a consumption which would be unnecessary if only the 0.5 MHz bandwidth were required.

2.1.6 Critical Life Elements

2.1.6.1 Mylar Belts

Seamless mylar belts are used to drive the headwheel and capstan assemblies. The physical properties of mylar make it particularly suitable for these applications. High speed applications are possible because of the high strength to weight ratio. Mylar has a high immunity to environment and its durability makes it highly reliable. Mylar belts also provide mechanical filtering, a property important to these applications.

The 28,800 rpm and 3,600 rpm headwheel speeds necessary for the high and low bandwidth modes of operation are achieved by a 1:1.2 step-up from a two-speed hysteresis synchronous motor. The capstan is driven through two reductions (each 5.6:1) for an overall ratio of 31.41:1.

Stress calculations (See Appendix B) based on the Goodman analysis show that all three belts have infinite life. Factors which would cause the life of a particular belt to become finite are:

1. Initial tension stress higher than that necessary to transfer the required torque.
2. Microscopic imperfections causing stress concentrations.
3. Unclean environment causing foreign material to wear through the belt while in contact with the pulley.

Properties of Mylar

Tensile Strength	$20 (10^3)$ psi
Yield Point (Head Treated)	$18 (10^3)$ psi
Tensile Modulus	$7.5 (10^5)$ psi
Density	1.39 gms/cc
Thermal Coefficient of Expansion	$15 (10^{-6})$ in./in./°F from 70° to 120°F
Service Temperature	-60°C to 150°C

2.1.6.2 Headwheel Life

Many parameters in the recording system influence head life. These include head-to-tape speed, tape tension, head contact area, head penetration, head and tape materials and tape wrap angle. These parameters were arranged during the development program to provide the minimum head wear consistent with good system performance. The head material selected was the same material (Alfecon) that is now employed in RCA's commercial television recorders. Several different tapes were evaluated with this head material and the most successful from the standpoint of performance and head wear was "3M" Type 888. Life data accumulated thus far has been extremely promising (see Figure 201) in comparison to the 350 hours presently averaged on commercial transverse scan video tape recorders. Although this trend can be rationalized to result from reduced head-to-tape pressure, it must be remembered that the data accumulated thus far represents an extremely small sample.

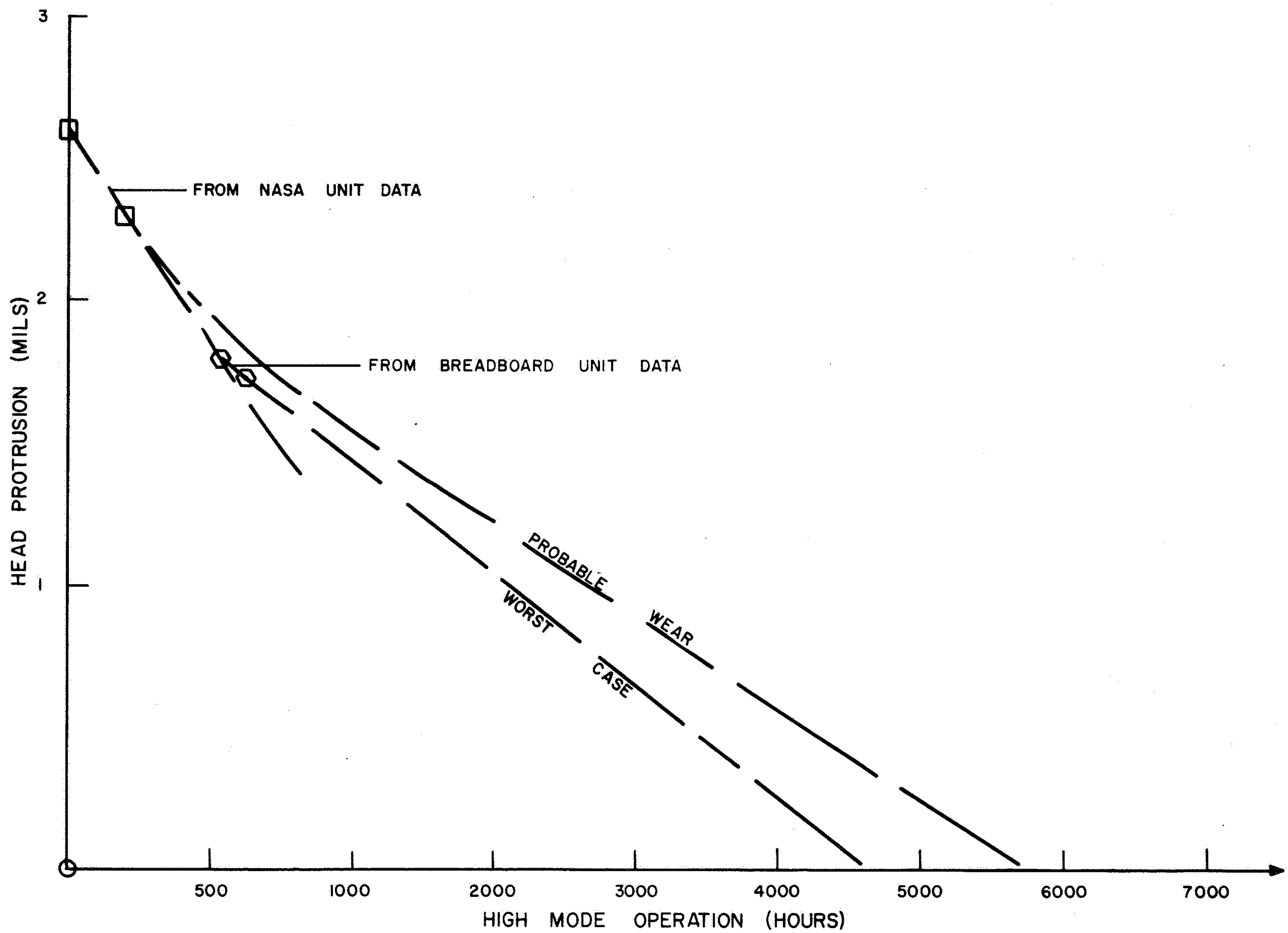


Figure 2-1. Projected Head Life

2.1.6.3 Tape Life

A reliable estimate of tape life cannot be made at this time because of the relative newness of the tape and recorder. Thus far, the worst cycling imposed amounts to about 400 passes and this has not resulted in any picture degradation. The new tape (3M888), unlike early tapes, has shown little tendency to flake or to "gunk" the heads.

Of some significance are the results obtained when the headwheel was allowed to scan stationary tape under normal running tension. With this arrangement a single strip of tape is scanned repetitively at the speed associated with normal record/reproduce. Under these conditions the tape was still intact after two minutes and the head first cut through the oxide in about 20 seconds. The twenty seconds of scanning represents about 20,000 head passes. This number gives some measure of tape life, without regard to deterioration of S/N, drop-outs, etc.

2.2 STRUCTURAL CASE AND COVER ASSEMBLY

The case and cover assembly is similar in design to that used on RCA's Gemini recorder which has proven reliable with respect to structural integrity and sealing capability. The structural gas-tight case and cover are fabricated from wrought magnesium for minimum weight and maximum rigidity and strength. The use of wrought alloys provides additional reliability and weight savings since it relieves the porosity problem and the requirement for higher design factors associated with cast alloys. Both case and cover are given an anodic coating for adequate protection against corrosion.

A ball -stem shock and vibration isolator, encapsulated in polyurethane rubber, is located in six positions on the case assembly. This isolation system would not be essential for equipment survival under design environment, but is considered essential for performance under high vibration levels. The isolation system also provides a convenient method for isolating the DC ground from equipment ground. One disadvantage of the isolation system, however, is that it minimizes thermal conduction so that a temperature rise of about 35°F occurs within the unit. Operation in an ambient of 100°F will result in an internal temperature which is near the limiting temperature (140-160°F) of the tape. To provide additional safety margin it may be necessary to provide external cooling or otherwise improve the heat conduction from the recorder.

To accommodate operation in a vacuum, the recording system has been completely sealed. This has been accomplished with an "O" ring gasket of viton rubber which is positioned around the periphery of the case in a precision groove. When the cover is bolted to the case, it applies pressure upon the "O" ring and insures a gas-tight seal. The signal connectors are similarly gasketed. Internal pressure can be and indeed has been maintained even when external pressure is reduced to essentially zero PSIA.

3.0 THE ELECTRONICS

The circuits developed during this program require, on the average, about 20% of the volume of the equivalent electronics in a standard broadcast television recorder. This reduction has been attained through use of integrated circuits to the maximum extent consistent with good design. A total of 64 integrated circuit packages are employed. Approximately half of the ICP's are of the TO5 construction and half of the flat pack variety. The 64 packages include 16 different types of integrated circuits. In addition to the active elements in the integrated circuits, 86 standard transistors are also employed in the recorder. Fifty of these standard elements are associated with the motor drives, ten with the record amplifier, and ten with the power supply system. The remaining 16 transistors are used throughout the video processing electronics for impedance matching and drives.

3.1 VIDEO INPUT PROCESSING

In the Record modes the Video Input sub-module in conjunction with the Video Level Monitor and Adjust Panel (located on the transport) provides input buffering, low pass filtering, and an indication of the peak level of the composite video input signal. The processed video input signal is applied to either the High Modulator (1A9) or Low Modulator (1A4). This sub-module is packaged on the same printed circuit card as the Limiter and is located in nest position 1A8. No sub-module interference occurs, however, since the Video Input sub-module is used only in Record and the Limiter sub-module is used only in Playback.

The Video amplifier within this sub-module is comprised of a Fairchild μA702A high gain, wideband DC amplifier. The μA702A is employed throughout the recorder in accordance with the three Fairchild application bulletins listed below:

(1) R. J. Widler, "A Monolithic Operational Amplifier," Fairchild APP-105/2, July, 1965.

(2) R. J. Widler, "The Improved μA702 Wideband DC Amplifier," Fairchild APP-111/2, July, 1965.

(3) J. N. Giles, "Frequency Compensation Techniques for an Integrated Operational Amplifier," Fairchild APP-117, August 1965.

3.1.1 Conclusions and Recommendations

3.1.1.1 Packaging

If sufficient nest space is made available, the Video Input sub-module should be packaged separately from the Limiter sub-module. Separation of these sub-modules will allow them to operate simultaneously and a "back-to-back" module check-out capability could then be incorporated. This would permit alignment and checkout of the Video Input, High Modulator, Low Modulator, Limiter, High Demodulator, Low Demodulator, and Video Output modules with the headwheel and tape stationary. Also, the playback electronics could then be energized in the record modes to monitor the signal being recorded. However, this would require several watts of additional power and is not generally necessary.

3.1.1.2 Meter and Potentiometer Relocation

The Video Level Adjust potentiometer and Video Level meter should be placed on the Remote Control panel to allow the operator to monitor and/or adjust the record video level with the recorder case and cover installed.

3.1.1.3 Filter Design Modification

The input and output filters employed in the recorder are purchased, encapsulated units. One of these filters was opened and examined during the program. Although the performance of the filters was good, they employed low quality parts and a packaging technique which was far from optimum for a space program. In future programs, active element, integrated circuit filters should be developed to replace the present LC design.

3.2 HIGH MODULATOR

In the HIGH RECORD mode the High Modulator, which is located in electronic nest position 1A9, will frequency modulate a high frequency carrier between 4.7 MHz and 7.1 MHz in accordance with the amplitude and frequency of the Video Input sub-module output signal. The High Modulator output signal is applied to the Record Amplifier.

A magnetic tape system cannot record and reproduce the DC levels and multi-octave range of frequencies contained within the video input signal. The wideband frequency modulation process converts the essentially infinite octave range of video input frequencies to a 2 decade FM spectrum (100 kHz to 10 MHz) that may be recorded by the 20 microhenry video head. The FM recording technique also provides for excellent video playback signal and amplitude stability. The off-tape playback signal is amplitude modulated due to variations in head to tape contact, dissimilarity between the two video heads and changes in the longitudinal tape speed that prevent the video heads from continually scanning along the center of the recorded video tracks. This playback signal amplitude modulation is rejected by the Limiter submodule portion of the frequency demodulation electronics.

The major High Modulator performance criteria are the undeviated FM carrier stability, deviation linearity, and FM spectrum fidelity (balance, distortion, and rejection of modulating frequency feedthrough components).

3.2.1 Carrier Stability and Linearity

A push-pull interconnection of similar, high frequency oscillators is employed within the High Modulator to enhance the undeviated FM carrier stability and effect a more linear relationship between video input signal amplitude and the instantaneous FM carrier frequency (deviation linearity). Short term carrier instability will contribute to the playback video noise level. A 2 db decrease in the amplitude of the undeviated 4.7 MHz FM carrier frequency was observed when the bandwidth of the filter at the input of a Rohde and Schwarz Selective Microvoltmeter was decreased from 5 kHz to 500 Hz. This indicates that the short term carrier stability is such that most of the spectral energy is contained within the 500 Hz bandwidth.

Long term carrier frequency drift which will affect the playback video DC level is primarily induced by temperature fluctuations within and/or between the high and low oscillator circuits. The long term carrier frequency drift observed in a temperature controlled chamber was less than 1.0 kHz per degree centigrade over a 25 to 55 degree range.

The High Modulator deviation linearity may be determined in several ways from Table 3-1 which tabulates the carrier frequency as a function of the DC level applied to the 50 ohm Video Input terminal on the Remote Control Panel.

3.2.2 Spectral Fidelity

For a 0 Vdc to +1.0 Vdc sinusoidal input frequency the High Modulator carrier frequency spectral component will be at 5.9 MHz, which is the center of the instantaneous FM carrier range. For a 4.0 MHz modulating frequency the amplitude of the first order lower spectral component at 1.9 MHz (-16 db with respect to component at 5.9 MHz) is 1.5 db greater than the first order upper spectral component at 9.9 MHz. Most of this essentially worst case unbalance is due to the high

TABLE 3-1. HIGH MODULATOR DEVIATION LINEARITY

Record Level (Vdc)	FM Carrier Frequency (MHz)	Frequency Change (kHz)
0.00	4.71	---
+0.20	5.18	470
+0.40	5.68	500
+0.60	6.18	500
+0.80	6.65	470
+1.00	7.13	480

frequency roll-off of the High Modulator output stage. An improvement in output stage bandwidth is not required, however, due to the Record/Playback frequency response which may be compensated by the Playback Amplifiers as prescribed in section 3.6 of this report. The amplitudes of the second harmonic of the FM spectrum, all spurious components and the 4.0 MHz modulating (video) signal feedthrough components are more than 38 db below the undeviated carrier frequency component at 5.9 MHz.

3.3 LOW MODULATOR

In the LOW RECORD mode the Low Modulator, which is located in electronic nest position 1A4, will frequency modulate a high frequency carrier between 588 kHz and 888 kHz in accordance with the amplitude and frequency of the Video Input sub-module output signal. The Low Modulator output signal is applied to the Record Amplifier.

The Low Modulator undeviated carrier frequency and peak deviation have been set to one-eighth those of the High Modulator to provide for the Record High/Playback Low and Record Low/Playback High modes of recorder operation without adjustment of the playback electronics.

The Low Modulator is very similar to the High Modulator and has essentially the same performance characteristics.

3.3.1 Carrier Stability and Linearity

The high frequency oscillators within the Low Modulator are set to one-eighth the oscillator frequencies within the High Modulator to provide essentially the same short and long term carrier stability. The long term carrier drift observed in a temperature controlled chamber was less than 200 Hz per degree centigrade over the 25 to 55 degree range.

The Low Modulator deviation linearity may be determined from Table 3-2 which tabulates the carrier frequency as a function of the DC level applied to the 50 ohm Video Input terminal on the Remote Control Panel.

TABLE 3-2. LOW MODULATOR DEVIATION LINEARITY

DC Level (Vdc)	FM Carrier Frequency (kHz)	Frequency Change (kHz)
0.00	587	---
0.20	648	61
0.40	708	60
0.60	765	57
0.80	828	63
0.10	888	60

3.3.2 Spectral Fidelity

The Low Modulator spectral fidelity is slightly better than that of the High Modulator. There is less than one db of difference between the amplitudes of the first order upper and lower spectral components for a 500 kHz modulating signal. The amplitudes of the second harmonic of the FM spectrum, all spurious components, and the 500 kHz modulating (video) signal feedthrough component are more than 40 db below the undeviated carrier frequency component.

3.4 RECORD AMPLIFIER

The record amplifier module is provided to amplify the FM record signal sufficiently to drive both video heads in the record modes. The amplifier is designed to deliver a maximum of 50 ma. peak-to-peak record current per head. This upper limit was determined by frequency response tests (See Figure 3-1) that were run to determine the relative head output versus frequency at various record levels. The results of these tests indicated that the optimum record current level is in the range of 35-40 ma peak-to-peak. This initial record level requirement will be reduced as the pole face depth of the heads decreased with wear. The amplifier is designed to give a flat wideband frequency response from 100 kHz to 8 MHz. To minimize the size and power of the module, the two video heads are driven in parallel. This is possible because an FM delay adjustment is not required for each head. The necessary power gain is provided by two parallel output stages. Separate gain adjustments are provided for HIGH/LOW record modes. A record transformer is used for each head to step up the signal level and provide a proper impedance match between the output stage and head.

The amplifier has been temperature tested at an upper ambient of +60°C with no observable degradation in performance. An extension of design effort on record amplifiers should investigate the possibility of operation from a single +28 volt nominal supply voltage as this would eliminate all requirements for a -22.5V regulated tap on the DC-DC converter.

3.5 DUAL PREAMPLIFIER

In the Record modes the Dual Preamplifier couples the two record transformer outputs through separate relays to video heads A and B. In the Playback modes the Dual Preamplifier provides 20 db of voltage amplification for each video head output. The Dual Preamplifier output signals are applied to the playback amplifiers within the Playback Amplifiers-Combiner module (1A3).

The Dual Preamplifier is contained within a shielded housing mounted on the transport in close proximity to the rotary transformer output on the video headwheel assembly. The leads between the rotary transformer outputs and the Dual Preamplifier (HDA High, HDA Low, HDB High, HDB Low) are kept short to minimize signal losses and radiated interference pick-up in High and Low Playback. The leads are unshielded to minimize the capacitance across the video heads. The capacitance across each video head (rotary transformer, wiring, relay contact, and Dual Preamplifier input capacitance) should be small to reduce record signal losses and to keep the frequency at which the 20 microhenry head inductance resonates with this capacity as high as possible. The head resonance is at approximately 7.1 MHz, the highest instantaneous FM carrier frequency employed.

The selection of the SE501K Video Amplifier for this moderate gain, wideband preamplifier application was based on the requirement for a compact integrated circuit unit with an output noise level competitive with conventional component units. Consider the following experimental data taken early in the Dual Preamplifier development cycle. The first portion of this data compares the V2 = V3 and V3 = V4

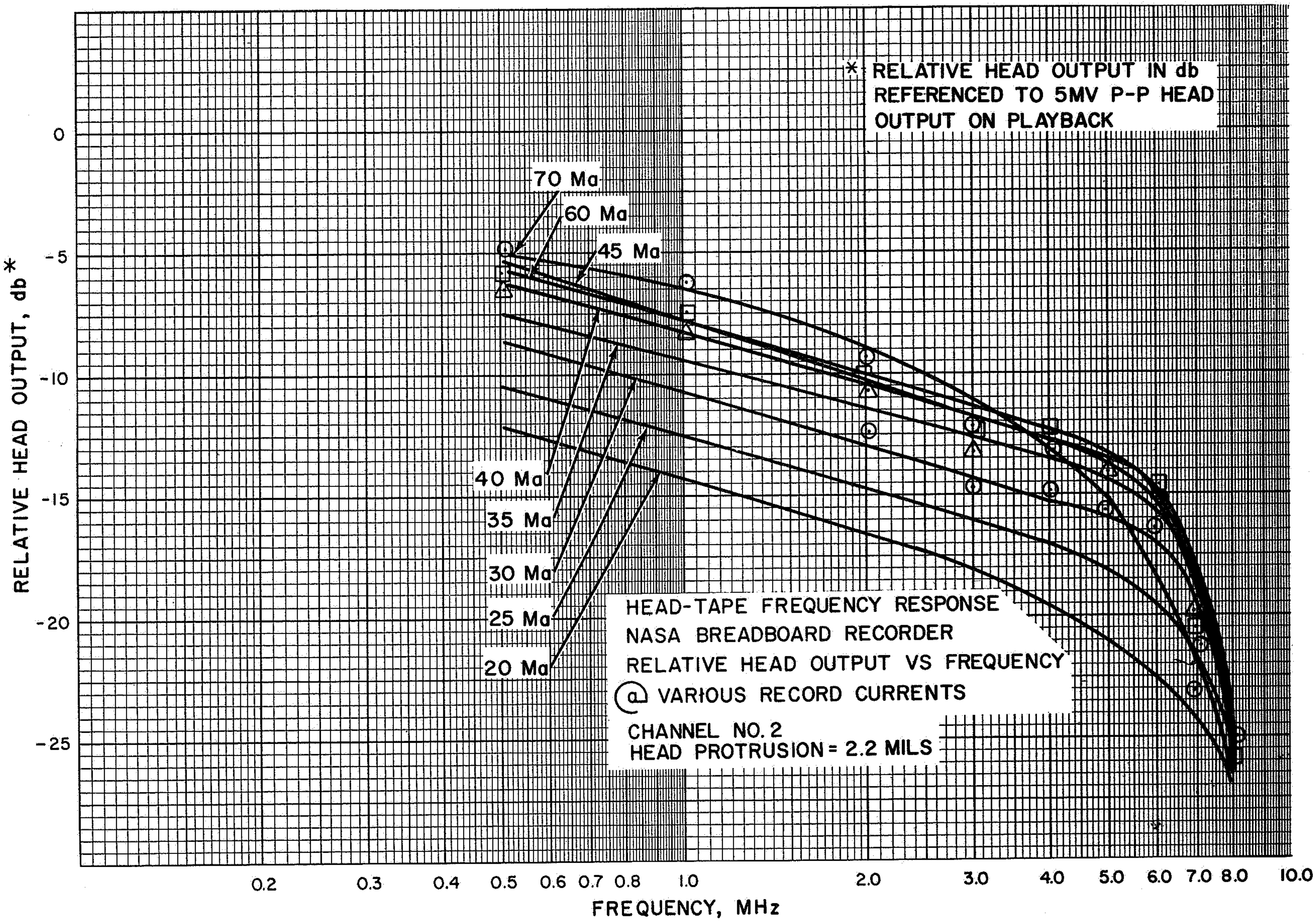


Figure 3-1. Integrated Circuit Pre-Amp Curves

interconnection configurations of the SE501K with the RCA CA3001 Video Amplifier, the only integrated circuit with a comparable noise level available at the time. The Integrated circuit preamplifier curves of Figure 3-2 point out that the two SE501K connection configurations have equivalent output signal-to-noise ratios (SNR) which are considerably better than the CA3001 output SNR. The second portion of the data (Figure 3-3) shows that the performance of the V2 = V3 SE501K configuration is comparable with an advanced conventional component preamplifier typical of those employed in wideband recording systems.

3.6 PLAYBACK AMPLIFIERS-COMBINER

The Playback Amplifiers-Combiner module amplifies and frequency compensates (equalizes) the two outputs of the Dual Preamplifier and then combines (commutates) these outputs to form a continuous FM signal. The combined output is applied to Limiter sub-module 1A8. The Playback Amplifiers-Combiner is located in electronic nest position 1A3.

Three RCA CA3001 Video Amplifiers are employed within each Playback Amplifier and throughout the Recorder in accordance with application note 1CAN5038, "Application of the RCA CA3001 Integrated Circuit Video Amplifier", dated November 1965.

Playback signal equalization is a primary function of the Playback Amplifier. Consider the High Record/High Playback FM spectral components of Figure 3-4. The first set of components represents the relative magnitude of the first order upper and lower spectral components measured at the Record Amplifier output. The undeviated FM carrier was set at 6.3 MHz and deviated between 5.6 and 7.1 MHz by 2, 3 and 4 MHz sinusoidal tones applied sequentially to the High Modulator (1A9) input. The second set of components represents the relative magnitude of these spectral components prior to playback equalization. It can be seen that the high frequency losses incurred in the Record/Playback process drastically alter the FM spectrum. The high equalization lead lag network within the Playback Amplifier attenuates the low frequency portion of the off tape signal to compensate for these losses.

The type and amount of compensation has been determined as follows. Consider a truncated FM spectrum consisting of the carrier and first order upper and lower spectral components. These are the only components that fall within the FM bandwidth at the higher modulating frequencies most influenced by Playback Amplifier equalization. Essentially all of the FM information is contained within these components due to the low modulation index ($MI = \Delta f/fm$) that applies. For example, with a 4.0 MHz video input frequency the $MI \leq 1.2/4.0 = 0.3$, where the peak FM carrier deviation (ΔF) is 1.2 MHz for the maximum input signal level. The comparatively low amplitude of the second order FM spectral components may be noted

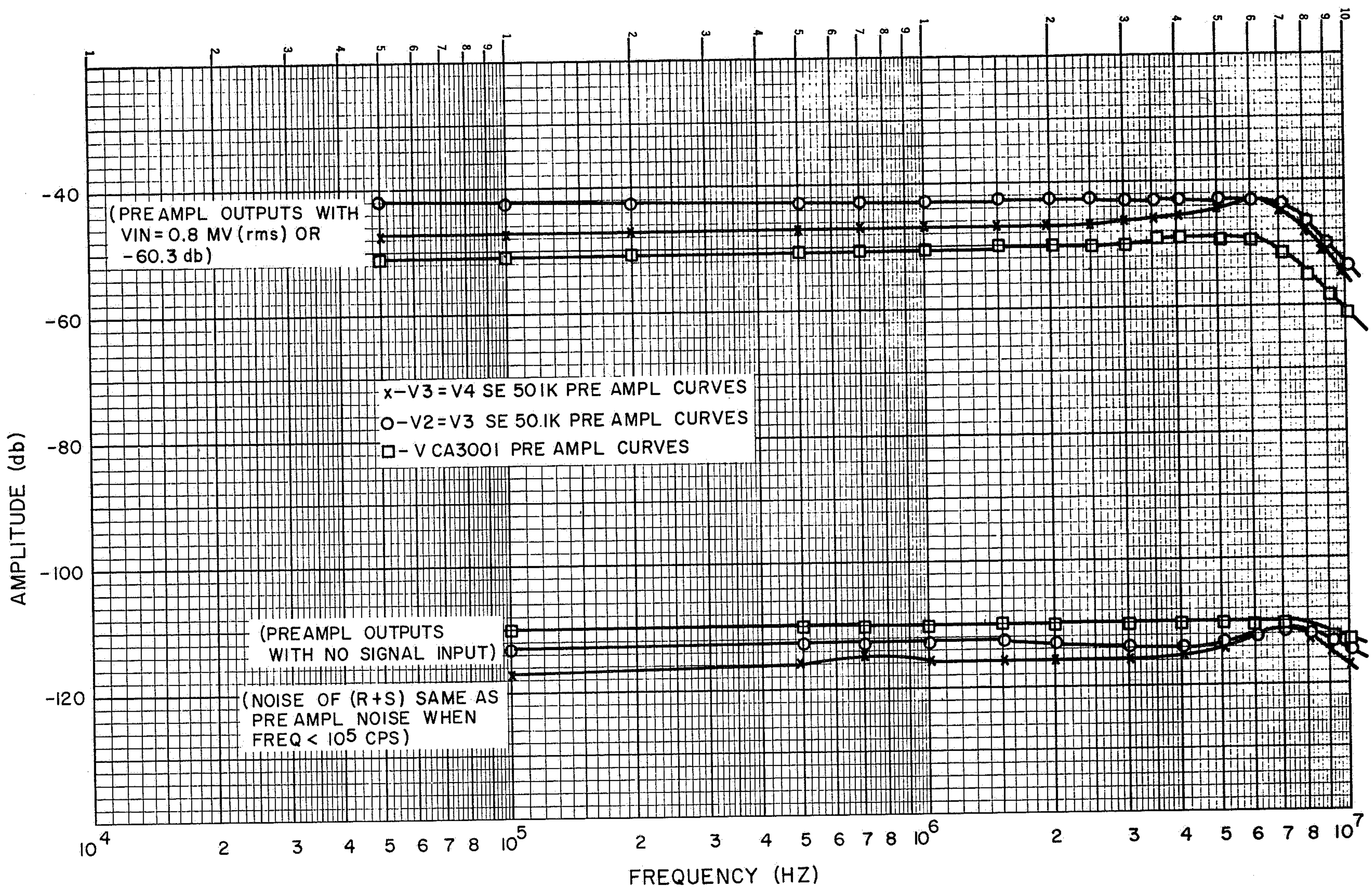


Figure 3-2. Conventional Pre-Amp vs SE501K Pre-Amp

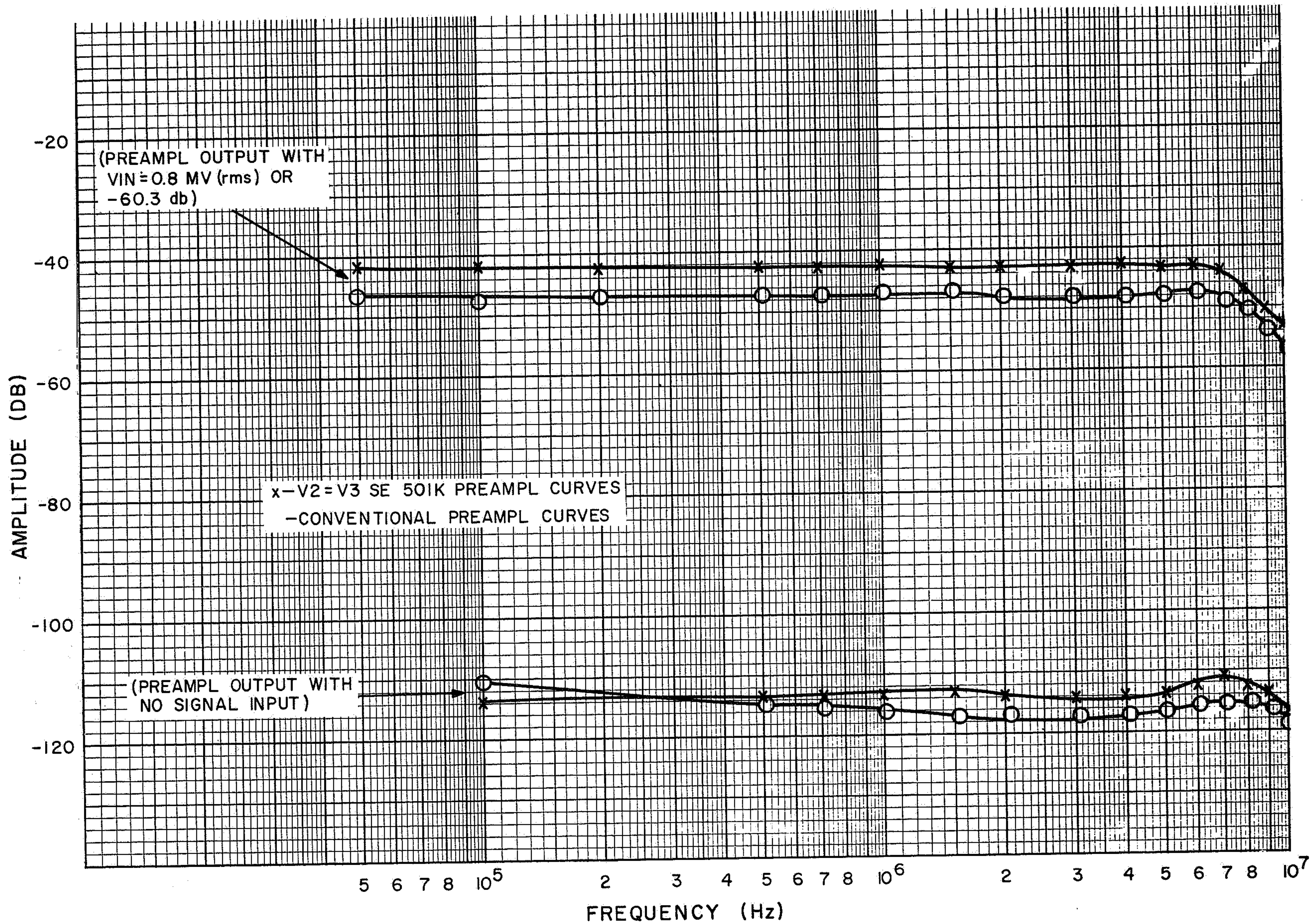


Figure 3-3. High Record/High Playback FM Spectra

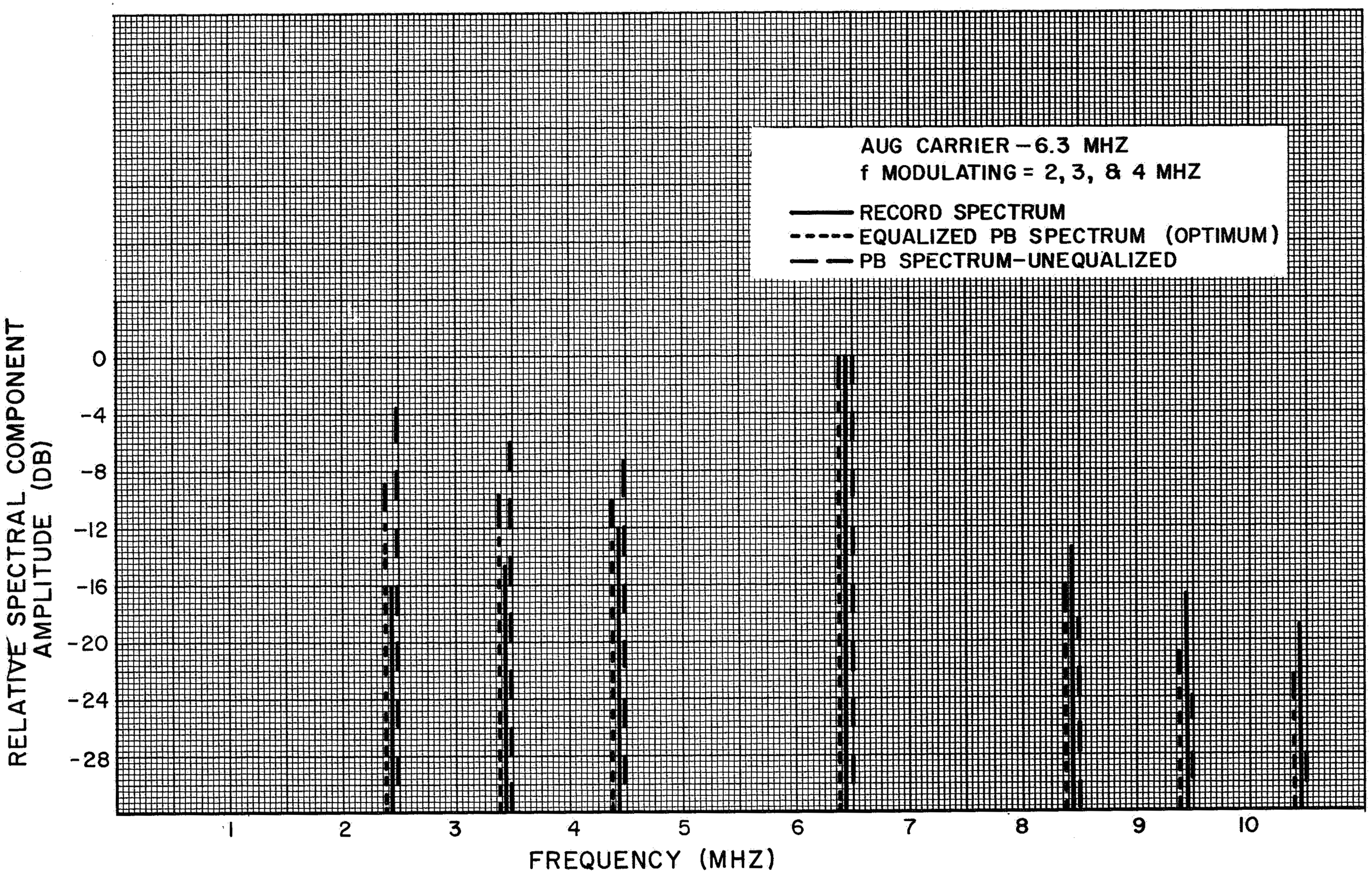


Figure 3-4. High Record/Low Playback FM Spectra

for this modulation index where the amplitude of the carrier, and first and second order FM spectral components are given by Bessel functions $J_0(MI)$, $J_1(MI)$ and $J_2(MI)$, respectively, as

$$J_0\,(0.3) = 0.98$$

$$J_1\,(0.3) = 0.15$$

$$J_2\,(0.3) = 0.01$$

If the truncated FM spectrum, given by $\rho(t) = J_0(MI) \cos \omega_c t + J_1(MI) \cos (\omega_c + \omega_m) t - J_1(MI) \cos (\omega_c - \omega_m) t$, is passed through a linear phase network with a linear amplitude response roll-off and unity gain at the carrier frequency, the amplitude of the first order lower spectral component will be increased and the amplitude of the first order upper spectral component will be decreased an equal amount and we obtain:

$$\rho'(t) = J_0\,(MI) \cos \omega_c t + (J_1\,(MI) - \alpha) \cos (\omega_c + \omega_m)\, t$$

$$- (J_1\,(MI) + \alpha) \cos (\omega_c - \omega_m)\, t$$

Now, $\rho'(t)$ may be considered as the addition of frequency and amplitude modulation spectral components given by

$$\rho'(t) = \rho\,(t)_{FM} + \rho\,(t)_{AM}\,,$$

where

$$\rho(t)_{FM} = (J_0\,(MI) + \alpha) \cos \omega_c t + J_1\,(MI) \cos (\omega_c + \omega_m)\, t$$

$$- J_1\,(MI) \cos (\omega_c - \omega_m)\, t$$

$$\rho\,(t)_{AM} = -\alpha \cos \omega_c t - \omega \cos (\omega_c + \omega_m) t - \alpha \cos (\omega_c - \omega_m) t$$

The Limiter sub-module will pass only the carrier frequency component of the AM spectrum and the resultant FM spectrum presented to the High Demodulator is given by:

$$\rho''(t) = \rho(t) = J_0(MI) \cos \omega_c t + J_1(MI) \cos (\omega_c + \omega_m) t - J_1(MI) \cos (\omega_c - \omega_m) t$$

It can be seen in Figure 3-4 that the spectral components amplitudes of the unequalized playback signal are quite similar to the $\rho'(t)$ spectrum at the output of the ideal linear roll-off network. The third set of spectral components in Figure 3-4 represents the optimum equalized FM playback spectrum (yields the best compromise between playback video bandwidth and SNR). The optimum equalized FM spectral components are close to the output of the ideal linear roll-off network than the unequalized spectral components. The equalized amplitude response would more closely resemble that for the ideal linear roll-off network if the high equalization network provided for independent playback signal amplitude response and phase response adjustments. Independent adjustment of these signal parameters would require a more sophisticated equalization network that could not be packaged on the module area allocated to the Playback Amplifier.

Consider the High Record/Low Playback spectral components of Figure 3-5, which correspond to those of Figure 3-4 except that the record components ($f_c = 6.3$ MHz and $f_m = 4.0$ MHz) are shifted downward in frequency by a factor of 8 to correspond to their playback equivalents. For this Low Playback case the optimum equalized amplitude response is essentially identical to that of the ideal linear roll-off network. This correlation may be attributed to the more linear phase response inherent in the Record High/Playback Low mode of system operation. The fact that the resonant frequency of the video heads is considerably above the playback frequency of interest is a major factor contributing to this improved phase response.

3.6.1 Conclusions and Recommendations

3.6.1.1 Improved Equalization

If sufficient nest space is made available, improved high and low equalization networks may be incorporated within the Playback Amplifiers. Relocation of the 2" x 1" Combiner to a Combiner-Limiter module should provide the necessary module space. The most advanced wideband recorder playback amplifiers accomplish equalization with a linear phase "cosine" equalizer, and a linear phase, a linear roll-off low pass filter. The "cosine" equalizer is a tapped delay line network that provides adjustable compensation, at constant phase, for the amplitude response roll-off incurred in the wideband Record/Playback process. The off tape playback signal amplitude response is essentially flat at the "cosine" equalizer output. The linear phase, linear roll-off filter is then employed to reduce the Playback Amplifier bandwidth and, hence, noise level to improve the playback video signal-to-noise ratio. It has been shown that this may be accomplished without significantly affecting the FM spectrum at the demodulator input.

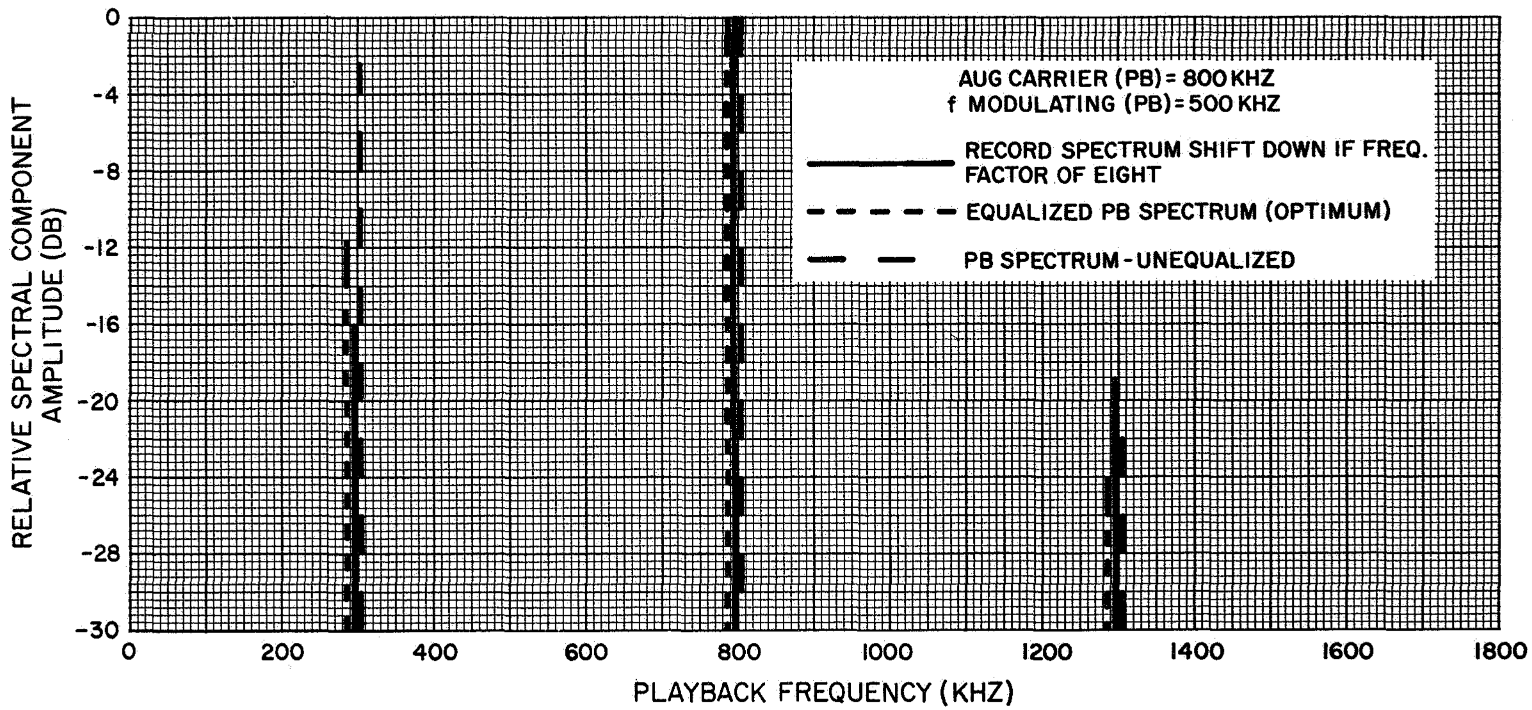


Figure 3-5. Low Demodulator Discriminator Curve

3.6.1.2 Double Ended Input Option

The Playback Amplifiers may be readily modified to accept a double ended input signal if the differential preamplifier configuration discussed in section 3.5 is adopted. The push-pull preamplifier output signal would be applied to both inputs of the differential pair within the Playback Amplifier input stage. In addition, this modification would increase the Playback Amplifier gain by 6 db and improve its common mode noise rejection properties.

3.7 LIMITER

The Limiter sub-module (1A8) accepts the recombined FM from the Playback Amplifier/Combiner (1A3), applies 50 db of hard limiting to eliminate effects of AM, and supplies normal and inverted waveforms to the Low Demodulator (1A2) or High Demodulator (1A1). The development of this sub-module had been completed before the development program covered by this contract and testing was limited to verifying operation at the low bandwidth.

3.8 LOW DEMODULATOR

The Low Demodulator regenerates video from the limited FM signal during low speed playback. Normal and inverted limited waveforms are received from the limiter sub-module (1A8). The demodulated output, which is derived by combining the two waveforms through a NOR gate, delaying with a one-shot, and suppressing carrier through a Golay filter, is applied to the video output module (1A7). The output of the demodulation with a sweep input is shown in Figure 3-6.

In designing the Low Demodulator, three approaches were considered. Each was evaluated on the basis of the delaying technique employed. The first approach called for the use of a coaxial cable as a signal delaying element. Inasmuch as the amount of delay required is inversely proportional to the FM carrier frequency, a long length of cable was needed - so long, in fact, as to be unmanageable in the limited space available.

The second approach called for the use of integrated circuit digital gates. This approach resulted in a more compact package, but required excessive power (since approximately 40 CD2101 flat packs were needed to provide the required delay.)

The final approach involved the use of an integrated delay multivibrator. With this approach both the power and space requirements were minimal. The General Instrument PC-18 One-Shot was selected since it provided a substantially constant pulse width output over the entire range of deviation frequencies.

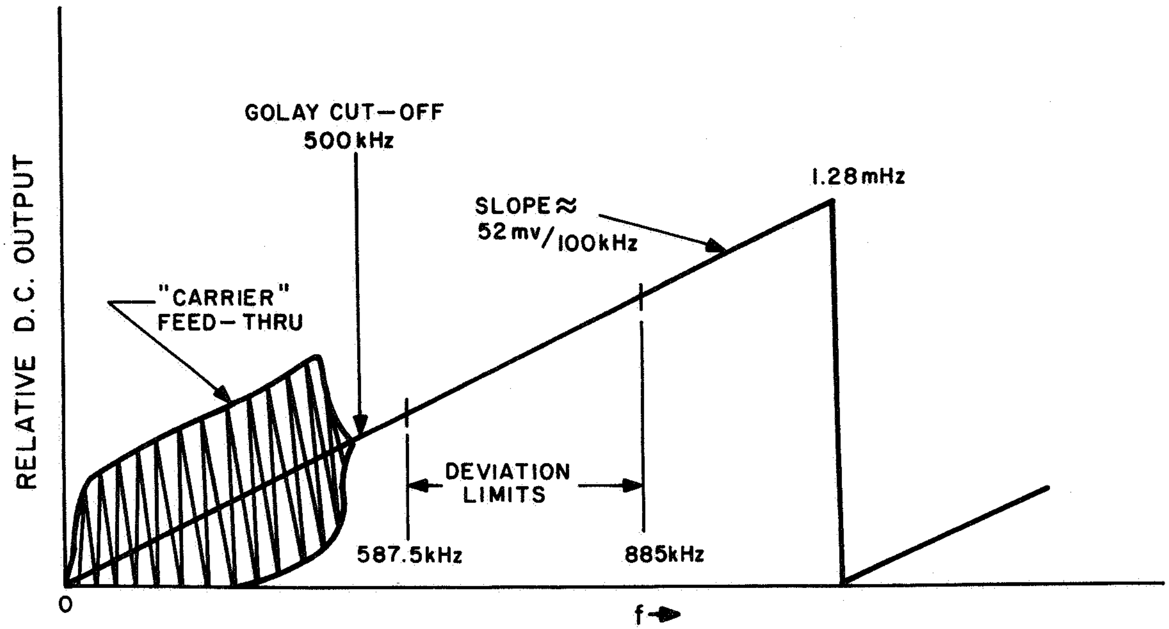


Figure 3-6. High Demodulator Discriminator Curve

The Golay Filter core form is wound with multilayers of 10 strand #36 Litz wire. A single layer core form (similar to that employed in the High Demodulator) would have been impractical due to excessive size. Solid wire was originally used in the filter, but the frequency response was so poor that a high frequency boost network would have been necessary. The Litz wire yielded the desired response without the boost network.

3.9 HIGH DEMODULATOR

The High Demodulator utilizes digital techniques to regenerate video from the limited FM signal during high speed playback. The normal and inverted limited waveforms are received from the Limiter sub-module (1A8). Subsequent combination through a NOR gate, and processing through a digital delay, half adder and Golay Filter yield the demodulated video which is applied to the video output module (1A7). The output of the High Demodulator for a sweep input is shown in Figure 3-7.

The primary considerations and compromises involved in the design of the High Demodulator were centered about the selection of components which would minimize the complexity and spatial requirements of the package, and in deciding on the appropriate mode of detection (i.e., first slope vs. second slope) to be employed.

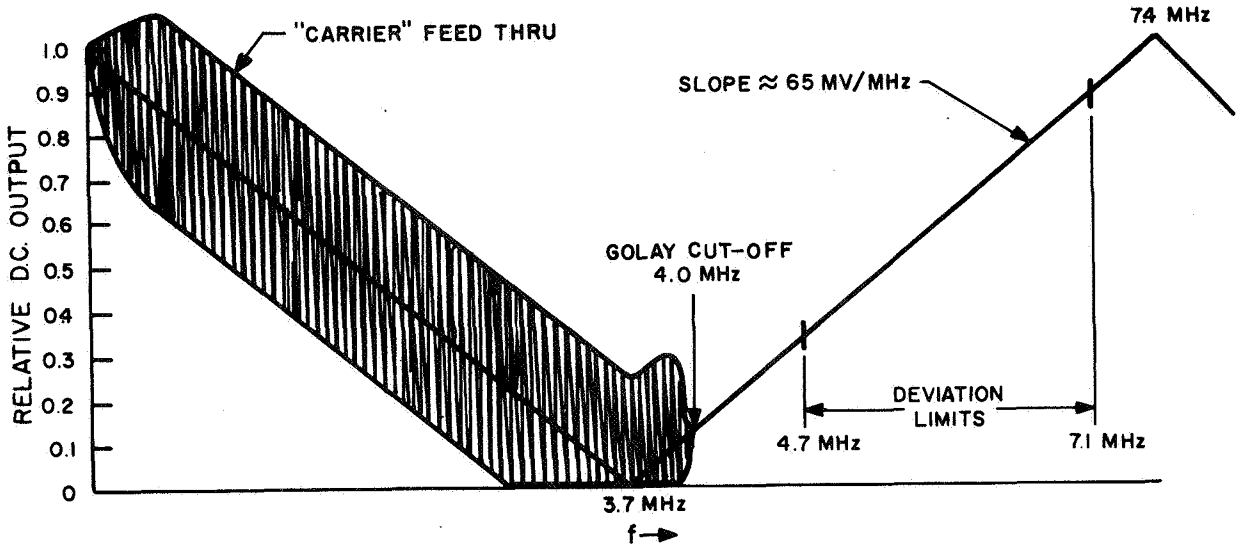


Figure 3-7. Block Diagram, Transient Suppression Electronics

Spatial limitations precluded the use of coaxial cable which had heretofore been used to perform the delaying function. The use of integrated circuit digital gates as delaying elements seemed to suggest a reasonable alternative. The first gates to be employed were contained in a Motorola MC359 package. These performed well, but only two gates were included in each flat pack and, as a result, 8 flat packs were needed to provide the 135 nanoseconds of delay required for second slope detection. In addition, these units required two supply voltages (i.e., - 5.2 volts and -1.55 volts). An RCA CD2101 flat pack proved to be an improved substitute, in that each flat pack required only a single supply and included four gates. This resulted in fewer packages, lesser wiring, lesser space and considerably fewer decoupling components.

Before deciding whether to use first or second slope detection, the properties of each method had to be investigated and evaluated. It was found that, if first slope detection was used, a reasonably flat back-to-back (i.e., modulator-limiter-demodulator) response was obtainable over the 4 MHz video bandwidth. This advantage was countered, however, by the fact that the sensitivity inherent in first slope detection is considerably less (1:3) than that inherent in second slope detection.

Second slope detection did not exhibit the flat back-to-back response observed in first slope detection, but it did offer an approximately 3:1 improvement in discriminator sensitivity. This improved sensitivity minimized carrier feed-thru and, as a result, improved the overall system signal-to-noise ratio.

In the final design, second slope detection prevailed over first slope detection. This selection was made on the premise that a slight degradation in back-to-back frequency response was a small price to pay for an improved signal-to-noise ratio.

3.10 VIDEO OUTPUT PROCESSING

In the Playback modes the Video Output module, in conjunction with seven selectable Output Filters located outside the electronic nest, provides the High Demodulator (1A1) or Low Demodulator (1A2) output signal amplification required to drive the selected Output Filter. It also provides video bandwidth limiting, and signal amplification to drive either the 100 ohm or 50 ohm Video Output terminal on the Remote Control Panel. The Video Output module is located in electronic nest position 1A7. The output filter may be selected for a particular mission in accordance with Table 3-3. Proper output filter selection will significantly improve the video playback signal-to-noise ratio.

TABLE 3-3. OUTPUT FILTER SELECTION

Specified Record Bandwidth	Record Speed	PB High Speed Filter SW Position	PB Low Speed Filter SW Position
DC - 4.0 MHz	HIGH	OPEN	OPEN
DC - 1.0 MHz	HIGH	1 MHz	125 kHz
DC - 500 kHz	HIGH LOW	560 kHz OPEN	70 kHz OPEN
DC - 250 kHz	HIGH LOW	250 kHz 2 MHz	70 kHz 250 kHz
DC - 125 kHz	LOW	1.0 MHz	125 kHz
DC - 70 kHz	LOW	560 kHz	70 kHz
DC - 25 kHz	LOW	250 kHz	25 kHz

For example, the Apollo 500 kHz TV format (10 frame/sec, 320 active lines/frame) has been recorded and reproduced with the following peak signal to rms noise ratios.

Case I Record Low/PB Low, Output Filter Selector Switch in OPEN position (LOW Demodulator Golay Filter used) SNR - 38 db.

Case II Record High/PB High, Output Filter Selector Switch in OPEN position (High Demodulator Golay Filter used) SNR - 38 db.

Case III Record High/PB High, Output Filter Selector Switch in 560 kHz position SNR - 54 db.

3.10.1 Observations and Recommendations

3.10.1.1 Output Filter Change

System size and weight would be reduced if the Output Filter Selector switch and the Output Filter bank were eliminated. An appropriate output filter would then be selected prior to a given mission and plugged into a socket located on or near the Video Output module.

3.10.1.2 Video Line Driver Modification

The video line driver could be redesigned as a current source capable of delivering a peak current of 20 milliamperes. In this manner the recorder output would more closely duplicate the video input signal sources (the video camera outputs) and would develop video levels of 0 - +1.0 Vdc and 0 - +2.0 Vdc into 50 ohm and 100 ohm loads, respectively.

3.10.1.3 Commutation Transient Suppression

At present the transients induced by video head commutation in playback are present in the video output signal. In HIGH PLAYBACK the switching transients vary between -0.5 Vdc and +1.5 Vdc on the 50 ohm Video Output Terminal, are 1.5 microseconds wide and occur at a 960 Hz rate (twice for each video headwheel rotation). In LOW PLAYBACK the transients vary between -0.5 Vdc and +1.5 Vdc, are 8 microseconds wide and occur at a 120 Hz rate. In each playback mode the loss of video information due to these head commutation transients is approximately one part in 10^3.

In broadcast quality television recorders, such as the Model TR-22 manufactured by RCA's Broadcast and Communications Products Division, a single video format is recorded. The video head overlap in these recorders (time interval during which 2 heads are simultaneously recording or playing back identical video information) is of sufficient length to contain a horizontal blanking signal. Video head commutation is effected during the first horizontal blanking signal that occurs after overlap is detected thereby preventing the appearance of commutation transients in the playback video display.

The many video formats that must be accommodated by the NASA Recorder prevent adaptation of the broadcast technique for commutation transient elimination. A second technique for transient elimination consists of continuous addition of the two video head outputs at the Playback Amplifier outputs. The composite playback signal would then, in theory, add to twice normal amplitude during the head overlap period. A third technique consists of gradual (fade) switching between the two Playback Amplifier outputs during the overlap period such that the total output signal amplitude does not change. This is more complicated than continuous addition but enhances the system signal to noise ratio. This is accomplished by blocking the electronic noise present at the Playback Amplifier output corresponding to the video head that is out of contact with the tape. However, both these techniques are adversely affected by the fact that during the overlap period the two video heads are in contact with opposite edges of the tape. Random changes in the video scan length induced by tape tension and temperature variations effect the phase relationship between the two head outputs. Experimental data taken on the NASA recorder indicated that the phase variation between output signals was considerable at the high ratio of FM carrier frequency to headwheel velocity employed. When this phase variation exceed approximately 120 degrees of the FM carrier frequency, the video SNR during the head overlap period deteriorated significantly and playback signal cancellation resulted as this phase variation approached 180 degrees. However, this method of commutation transient suppression appears feasible for the lower ratios of recorded frequency to headwheel velocity that would be employed for continuous diphase recording of digital information.

Although it does not appear that commutation transients may be eliminated on the NASA Recorder, they may be effectively suppressed (Squelched) by incorporating a shunt connected analog switch in the Video Output module.

A Type C (enhancement mode), N-channel insulated gate field effect transistor (IGFET) similar to the Motorola 2N4351 could be used as the switch. Figure 3-8 is a block diagram of a Squelch electronics scheme consisting of the switch and its associated digital timing circuitry. The squelch timing may be determined by applying the Gate HD-A ON and Gate HD-B ON video head commutation signals to the Video Output module. These gates are presently developed by the Reference and Timing module (1A5) to switch the Combiner within the Playback Amplifier-Combiner module (1A3). The negative going edges of these complementary square-wave signals may be differentiated to form a negative going pulse train that will trigger Squelch Delay monostable multivibrator Z1 at each head commutation. The output of Z1 would then be delayed to compensate for the time required for the head commutation transient to propagate through the Limiter, High or Low Demodulator and part of the Video

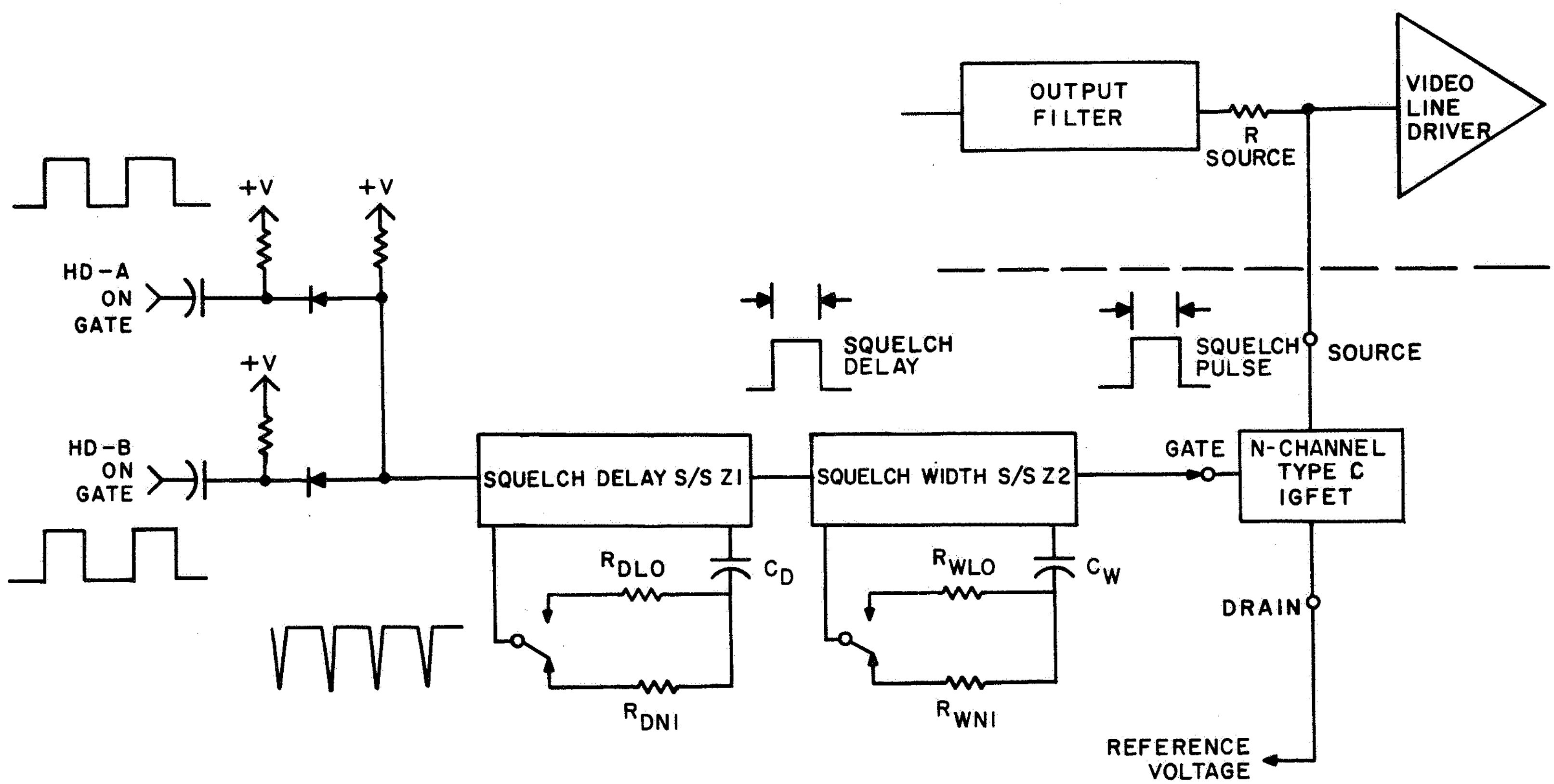


Figure 3-8. Diode Suppression Circuit

Output modules. This propagation time compensation would be set by external timing elements C_D and R_{DH1} to approximately 1 microsecond in HIGH PLAYBACK and set by C_D and R_{DLO} to approximately 8 microseconds in LOW PLAYBACK. The start of the squelch interval would be set by Z1 and the squelch width would be determined by Squelch Width monostable multivibrator Z2. This width would be set by C_W and R_{WHI} to 1.5 microseconds in HIGH PLAYBACK and set by C_W and R_{WIL} 8 microseconds in LOW PLAYBACK. Monostable multivibrators Z1 and Z2 may be integrated units such as the Fairchild DT μ L951 or may be constructed by interconnecting various logic gates. Some techniques for logic gate interconnection are given by R. D. Ricks, "Using Fairchild Integrated Circuits as Monostable Multivibrators," Fairchild APP 106, October 1965. The positive squelch pulse output of Z2 may be applied to the gate input of the N-channel IGFET (Analog Switch) to reduce the impedance between the source and drain treminals from essentially an open circuit to less than one hundred ohms. For maximum effectiveness the analog switch input source resistor R_s and the Line Driver input impedance should be relatively large. The analog switch drain terminal may be returned to a small reference potential. This potential will place the attenuated commutation transients (attenuation > 20 db) upon a video grey level pedestal where they will not interfere with video synchronization or introduce white disturbances in the playback video display.

3.11 REFERENCE AND TIMING

The Reference and Timing module contains a stable 320 Hz ± 0.005% tuning fork reference that is used as the basic oscillator to derive the headwheel and capstan motor drive frequencies. The 400 Hz, 2 phase and 100 Hz, 2 phase motor drives are obtained by digital divide by two and shift register stages. Miniature TO-5 case relays are used for switching the motor drives to the appropriate frequency and source in the various run modes. The digital circuits used are DTL (diode-transistor-logic) circuits. After an evaluation of DCTL, ECTL, RCTL, and DTL digital circuits, DTL was chosen as the preferable type due to its high noise immunity, good frequency response, low power, and availability from a number of vendors.

Servo reference and video switch gate timing are provided by a tone wheel mounted on the headwheel shaft. Once-around headwheel information is generated by a single notch in the tonewheel that changes the magnetic reluctance in the permanent magnet tonewheel heads. A single bipolar pulse is generated in the tonewheel head for each revolution of the tonewheel. Two heads are located 180 degrees apart to give the phase information. The pulses from the tonewheel heads are sensed by level detectors on the reference and timing board and reconstituted to a square-wave output. This output is used to provide the drive and timing for the FM combining during playback. The processed tonewheel output is also used to drive a one-shot multivibrator. The output of the one-shot multivibrator drives the control track record amplifier. There are two areas that should be pursued to further reduce the power dissipated by this module. An overall reduction in power is possible by using integrated circuits with lower dissipation that have become available after this module was designed. A further power saving could be attained with increased reliability by switching the signals with digital gates rather than relays; however, this would entail the generation of dual command voltages.

3.12 MOTOR DRIVERS

Two separate, but identical, motor driver sub-modules are employed to supply 2-phase power to drive the headwheel and capstan motors in the various "run" modes of operation. Each sub-module consists of two identical driver switches which supply power to the 0° and 90° motor phases. Since both the headwheel and capstan motors are supplied with square wave power, the driver switches are highly efficient (i. e., operation of the output stages is confined to the saturation and cut-off regions).

The basic driver switch is a bridge with balanced Darlington outputs. The inherent advantages of this configuration are threefold:

(1) The need for output capacitive coupling is obviated, since no net DC flows through the motor load.

(2) The peak-to-peak output voltage swing is twice the nominal 28 volt supply voltage, less small saturation drops in the conducting Darlington pairs.

(3) Only a single source supply is needed.

In the absence of a MOTOR RUN command, the inverted and non-inverted inputs to the motor driver are shorted to ground via relay contacts. This action prevents the driver output stages from conducting in the Stop modes.

In the course of the development program, it was found that differences in the switching speeds of the output transistors allowed simultaneous conduction. When this occurred, a very low impedance path would result between the two supplies and current spikes in the order of 10 to 20 amps would develop.

This was cured by slowing down the turn-on time of the transistors with capacitors across the input. Although this affected both rise and fall times, it provided sufficient delay to prevent simultaneous conduction. The size of the capacitors was chosen so that the delay was less than the time required for the inductive kick of the motor to fade out. With this selection the motor is not affected by the delay since the drivers do not deliver current during this interval.

3.13 RAMP START CIRCUIT

When either the High Speed Record or High Speed Playback mode is selected, the 2 pole windings of the headwheel motor are initially driven from a voltage controlled oscillator source. The frequency of this oscillator is controlled by a DC ramp input to provide 121 to 420 Hz power to the headwheel motor. The synchronous speed of the headwheel motor follows the ramping drive frequency from 121 Hz, until it reaches 400 Hz. At this time, the headwheel drive source is switched (via coincident detector logic on the Capstan Servo module) from the ramping VCO to a 400 Hz tuning fork reference. Once this transition is made, the tuning fork reference is permanently connected to supply a stable 2 phase, 400 Hz drive to the headwheel motor. The ramping frequency drive which synchronously accelerates the motor to speed is employed because it produces a significant increase in pull-out torque. To understand the mechanism involved requires that the reader be familiar with various characteristics of the hysteresis synchronous motor in general, and the headwheel motor in particular. To begin with, the pull-out torque of a hysteresis synchronous motor operating in the synchronous mode is directly proportional to the energy stored in the rotor at the instant at which synchronous speed is attained. This "residual energy" is in turn conditioned by the inertial load on the motor as it accelerates to synchronous speed (i. e., as the inertial load increases, the residual energy available at synchronism decreases). As a result, if a load having significant inertia is to be accelerated to a high synchronous speed, either the inertia itself must be reduced or the effects of inertial loading must be reduced. In the recorder, the overall inertia of the headwheel assembly is intended to be high so as to minimize the effect of load disturbances, and thereby optimize time base stability. As a result, little can be done to reduce the inertia directly. Obviously then we are left with the alternative of reducing the effect of inertial loading. In using the ramp generator to accelerate the headwheel motor in the High Speed modes of operation, the drive to the motor starts at 120 Hz. The motor quickly attains a synchronous speed commensurate with this low frequency input. Once this occurs the rotor is still strongly magnetized and motor operation is transferred to the synchronous mode. The slope of the frequency ramp is adjusted such that, as the frequency increases from 120 Hz to the switch-over frequency of 400 Hz, the headwheel motor will accelerate synchronously until an equivalent 400 Hz speed is attained. The overall result is a considerable improvement in steady state pull-out torque.

The ramp generator incorporates a ramp driven voltage controlled oscillator to generate equivalent 121 Hz to 420 Hz motor drives. On receipt of a RAMP START command, the frequency of the ramp generator increases exponentially from its low frequency limit to its high frequency limit. The output of the ramp generator is applied to one of two inputs of a coincidence detector. The remaining detector input is supplied from an equivalent 400 Hz motor drive source on the Reference and Timing Generator module. The coincidence detector passes the ramp generator input so long as its frequency is less than that of the reference input. Once the frequency of the ramp input has increased to the point where it is slightly greater than that of the reference input, the coincidence detector inhibits the ramp input and passes, instead, the reference input.

The output of the coincidence detector is employed as a source for the drives to the headwheel motor in the High Speed modes and the capstan motor in the Rewind mode.

Using the ramping frequency drive as explained earlier, the following torque measurements were taken on the high speed headwheel motor:

a) 28 volts dc, torque = 1.09 in.-oz.

b) 26 volts dc, torque = 0.968 in.-oz.

c) 24 volts dc, torque = 0.877 in.-oz.

All of the above measurements were taken with the motor initially loaded with a torque load of from 0 to 0.3 oz. Apparently, with this scheme, the initial ramp load has negligible effect on the eventual pull-out torque of the motor.

3.14 CAPSTAN SERVO

The capstan motor used in this recorder is a two phase hysteresis synchronous motor. In the record mode the motor is driven from the tuning fork reference. Because of the inherent time base stability of this motor, no attempt is made to servo in record. During the record process, a tonewheel pulse (indicating once-around speed of the headwheel motor) is recorded on a longitudinal channel called control track. During playback the control track signal, which indicates video head position in record, is phase-compared to the tonewheel, which indicates video head position in playback. Maximum playback signal will be obtained when the video head in playback coincides with the recorded video track. The capstan servo controls the positioning of the tape so that maximum playback signal will occur. Originally, a single flip-flop, in the reference and timing module, was used as the phase detector. A tonewheel pulse during playback would trigger the flip-flop into its one or high voltage state and a control track pulse would trigger the flip-flop into the 0 or low voltage state. When the control track and tonewheel were at the same frequency, the duty cycle of the voltage waveform would indicate the phase relationship between the tonewheel in record and in playback.

Systems checking of the capstan servo indicated that the flip-flop phase detector would not be adequate. If the control track pulses and the tonewheel pulses differed in frequency by any considerable amount, the error signal from the phase detector would be occurring at this difference or run-through rate. Since the bandwidth of the servo is low, the servo could not respond to this rate and, hence, the servo could not lock-up on its own. This problem was overcome by means of the following 3 flip-flop scheme.

The control track and processed tonewheel inputs are applied to an error detector composed of three flip-flops and an inverter. If two or more successive tonewheel transitions are applied to the detector in the absence of a control track pulse, the detector generates a "1" or high output to indicate a longitudinal tape underspeed condition. Conversely, if two or more successive control track pulses are applied to the detector in the absence of a tonewheel transition, the detector generates a "O" or low output to indicate a longitudinal tape overspeed condition. Finally, as the rate of the control track input varies about the rate of the tonewheel input, the duty cycle (and hence the average DC level) of the detector output will vary about a nominal average level, indicating correct longitudinal tape speed, and phase.

The capstan servo module was placed in a heat box during systems checking. Servo response and worst case jitter amplitudes did not change under the full range of temperature (0 to 60°C). The tracking position did change by approximately 20 to 49 μsec; however, this is negligible compared to the nominal jitter amplitude of about 200 μsec peak-to-peak.

A wider bandwidth servo system with motor damping could have been provided with the recorder; however, the additional time base stability that would have been gained was not required for this recorder. In addition, the wider bandwidth system would require additional power and size, both of which were not available.

3.15 CONTROL TRACK AMPLIFIER

In record mode the control track module provides for longitudinal track recording of pulses which are generated by the tonewheel amplifier and one-shot multivibrator at the once-around rate of the headwheel. In playback mode, the control track module reproduces the recorded pulses, and amplifies and shapes them for use by the capstan servo to control the tape speed and phase. Power is applied to the record amplifier only in the record mode to prevent any spurious output in the playback mode. The record input voltage also energizes a relay, switching the control track head from the playback input to the record output electronics. A pulse saturation recording technique is used with the pulse width optimized in High/Low record modes for maximum playback signal. In playback, two stages of amplification are required to obtain a useable off-tape signal in the Low 1-1/4 ips) playback mode. The playback section was designed to maintain a clean base line in the High playback mode (10 ips) without a reduction in the overall gain, thus eliminating the need for an additional relay.

A level detector is used to threshold the linear output and present the correct voltage levels and drive to the digital phase error detector in the capstan servo loop.

Further design effort should be directed toward a more sophisticated control track design utilizing a phase locked oscillator to correct an inherent problem associated with the capstan digital phase error detector. Loss of a single control track pulse due to a bad section of tape causes the capstan servo loop to drop out with a resulting temporary loss of video information. Incorporation of a phase locked oscillator (PLO) as part of the control track amplifier would minimize control track drop-out and loss of video information.

3.16 CONTROLS

The Recorder is controlled from the Remote Control Panel where a given mode selection will ground appropriate pins on the Power and Control connector located on the Recorder Case. The control system consists of the Remote Control Panel attached to the end of a twelve foot cable, an Internal Controls card mounted on the front of the electronic nest, and the Headwheel and Capstan Motors Control Interface card mounted on the side of the Motor Driver Assembly.

3.16.1 Remote Control Panel

All Recorder Commands are initiated from, and the Recorder status is monitored at, the Remote Control Panel. In addition, all signal leads and the +28 Vdc power supply are applied to the Recorder through the Remote Control Panel. The Recorder may, therefore, be operated within test facilities located up to 12 feet away from the Panel. The remote control approach will also facilitate integration of the Recorder with larger video systems that are controlled and monitored at a single point.

3.16.2 Internal Controls Card

The Internal Controls card energizes relays and distributes supply voltages throughout the Recorder in accordance with the mode commands generated at the Remote Control Panel. In addition, the Internal Controls card disconnects the Recorder from a low supply voltage, sets the time at which power is transferred between motor start and run windings and interlocks the recorder during the start and end of tape conditions.

3.16.3 Headwheel and Capstan Motors Interface Card

The Headwheel and Capstan Motors Interface Card relays respond to commands generated by the Internal Controls Card to switch the outputs of the Capstan and Headwheel Motor Drivers to the appropriate motor windings.

3.16.4 Observations and Recommendations

3.16.4.1 Remote Control Panel

The recorder could more readily be integrated into larger video systems if the Video Level Adj. potentiometer and Video Level meter were placed on the Remote Control Panel (See Recommendations in Section 3.1) and the Video Output filter was selected on a pre-mission basis (See Recommendations in Section 3.10).

The Start of Tape and End of Tape conditions are presently indicated on the Remote Control Panel. However, tape position within a given recording is not presently indicated. Tape position could be determined by monitoring the supply reel diameter with a spring loaded tracking arm and wheel mechanism that would place a tracking wheel in constant contact with the tape. A voltage could then be developed from the tracking arm position and applied to a tape Position Indicator located on the Remote Control Panel.

The tape position could be more accurately indexed by recording a time code along a longitudinal tape track. The Record mode time information could then be decoded in Playback. The spare longitudinal tape track within the Recorder could be used for tape indexing purposes. However, sufficient room is not presently available to accommodate the necessary record and playback electronics. The encoding, decoding and display circuitry would, in all probability, be located external to the Recorder.

3.16.4.2 Internal Controls Card

The Headwheel and Capstan Motors commence start-up simultaneously with a peak surge current of up to 9 amperes. After approximately 5 seconds (the duration of the Capstan motor start interval) this current drops significantly. The magnitude of the peak start current could be significantly reduced if the Internal Controls card were modified such that the Headwheel motor would commence acceleration after power is switched to the Capstan motor run windings. In the Low modes the total motor acceleration time would be doubled to 10 seconds. In the High modes the 45 second total motor acceleration time would be increased by 5 seconds. Rewind surge current would also be reduced, but Rewind time would not be affected by this modification.

The output stages of the Headwheel and/or Capstan Motor Driver cards may fail if the Mode Selector switch on the Remote Control Panel is rotated while either motor is accelerating. A warning notice has been placed on the Remote Control Panel; however, appropriate delay circuitry should be incorporated on future Internal Controls Cards to eliminate this failure mode.

Power Supply and component switching for various modes of Recorder operation is accomplished by miniature SPDT (Teledyne Type 411-26) and DPDT (Teledyne Type 412-26) relays. These relays switch considerably less than their rated contact current and are energized well above their minimum rated coil voltage. However, several relay failures have occurred. These relays should be fully investigated before they are considered for a flight recorder.① No second source of TO-5 transistor can size relays has been established.

Larger relays may be required to enhance system reliability. If this is the case, considerable electronic repackaging will be required. A review of the system design indicates that the relay count cannot be significantly reduced. The larger relays (Allied Type S-6A1), used on the Headwheel and Capstan Motor Controls Interface Card and for system low voltage power protection, have performed reliably.

3.17 DC-to-DC CONVERTER

A dc/dc converter is used to efficiently provide +8V, -8V, +5.6V, and -22.5V for the electronic circuitry. The converter consists of a two-transformer, Jensen-type, self-oscillating converter with multiple outputs, each followed by full wave rectifiers and 3 half-section LC filters. The circuit was chosen for its proven reliable operation and simplicity.

A linear transformer is used to couple the output to the load. Because the output transformer is not allowed to saturate, the peak current of the driver transistors is determined primarily by the output load impedance. A greater efficiency is obtained with a two transformer design by eliminating the large magnitude current spikes that would be present in a single transformer version. The converter's 100 kHz switching frequency is set by the second transformer operating in a saturated mode at the reduced base drive power level. The efficiency of the converter was measured as 75% at an input power level of 20 watts.

A series voltage regulator is also included as part of the power supply package. It incorporates closed loop control to maintain a +22.5 volt output for all input supply voltages in the range of +24 to +32V dc. The regulator and converter are housed in a donut-shaped package that provides RFI shielding from the converter's 100 kHz switching rate. The complete package was temperature tested at an upper ambient of +60°C driving a full load. The unit is mounted underneath the reel assembly.

Further design effort in power conversion should investigate the relative size, weight, efficiency, regulation, response and output ripple of the existing design as compared to the characteristics obtainable with a variable frequency, variable duty cycle type of energy converter.

① See Failure Analysis Memo in Appendix C

3.18 TRANSIENT SUPPRESSION CIRCUITRY

The recorder incorporates three identical half-section LC filters (location 14) to suppress transients on the nominal +28 Vdc incoming power line. The outputs of two of these filters are separately coupled to the Capstan and Headwheel Motor Drivers. The remaining filter output is applied to the Power Supply module via a low voltage protection circuit on the Internal Controls module.

Two different circuits were initially considered and evaluated for use in suppressing the following specified power line transients:

(a) Positive — 78 volts for 10 microseconds at 10 pps repetition rate.

(2) Negative — 100 volts for 10 microseconds at 10 pps repetition rate.

The first circuit considered involved the use of semiconductor diodes and a storage capacitor (see Figure 3-9). This circuit utilizes CR1 to disconnect power to the recorder when negative transients drive the input supply voltage below ground potential. C1 is provided to maintain a continuous supply voltage to the recorder during this brief disconnect period (i. e., 10 microseconds). Positive transients are suppressed via Zener breakdown of diode VR1. In the absence of more definitive information regarding the nature of the positive transient voltage source, it was impossible to predict the effect it might have on the peak current requirements for both CR1 and VR1. It is conceivable that, if the positive transient source is an inherently low impedance generator (i. e., a voltage source), permanent damage to either CR1 and/or VR1 could result. It was concluded, therefore, that the diode suppression circuit would be unacceptable for use in the recorder.

The second transient suppression circuit considered, and later selected for use, consists of a simple half-section LC filter (see Figure 3-10). The break point of the filter was selected to be as low as practicable in keeping with the physical space available in the recorder. In selecting the inductor, square loop core material was avoided so as to insure against saturation and subsequent loss of inductance at high DC magnetizing current levels.

Initially a single LC filter was planned for the recorder; however, during the development program an interplay was found to exist between the two motor drivers when the switching varied in phase. This interplay was eliminated by incorporating the three independent LC filters.

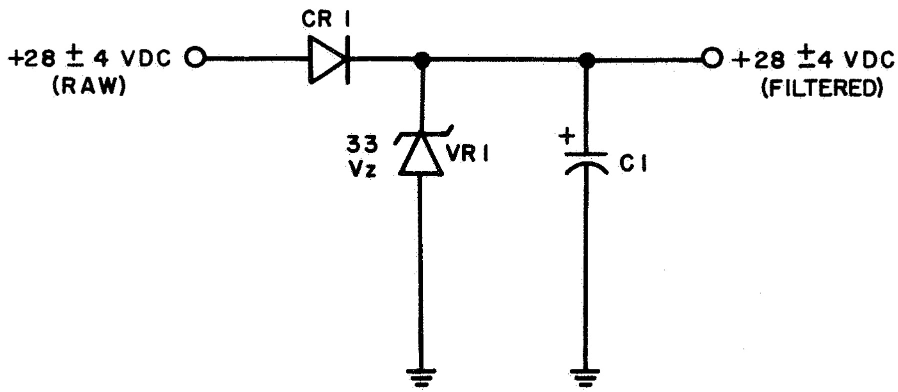


Figure 3-9. LC Suppression Circuit

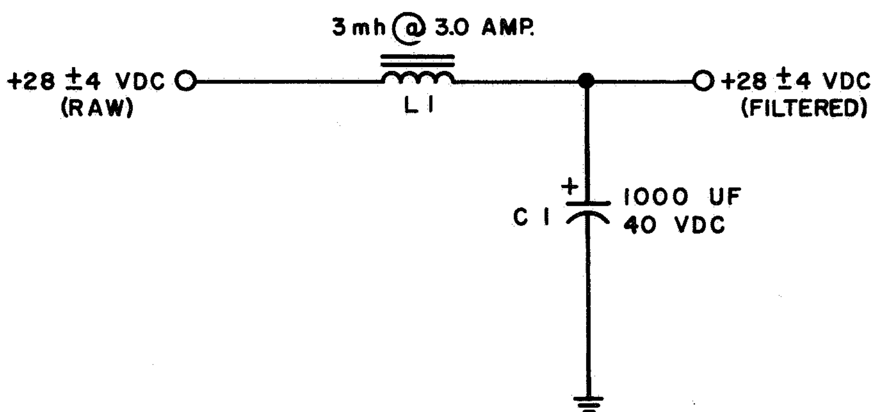


Figure 3-10. LC Suppression Circuit

4.0 EVALUATION TESTS

4.1 SYSTEM EVALUATION TESTING

Extensive testing has been conducted to determine the design trade-offs and corrections required to optimize the performance of the Recorder. The important factors influencing system performance and the significant design trade-offs made during system development are discussed in the following paragraphs.

4.1.1 Record/Playback Bandwidth

4.1.1.1 High Frequency Characteristics

The Recorder high frequency response extends to 500 kHz in the low speed modes and 4.0 MHz in the high speed modes. The playback video bandwidth is influenced by the bandwidth of the video portions of the record and playback electronics, the bandwidth and phase response of the FM portions of the record and playback electronics, and the bandwidth and phase response of the Record/Playback process.

The record video electronics are comprised of the Video Level Monitor and Adjust panel, the Video Input sub-module and the input stages of the High Modulator and Low Modulator. The playback video electronics are comprised of the High Demodulator and Low Demodulator Golay filter networks, the Video Output module and the selectable Output Filters. The combined amplitude response of these video electronics is down 3 dB at 500 kHz for the low modes and 4.0 MHz for the high modes. To achieve this, the amplitude response of the low and high input filters within the Video Input sub-module is down only 1 dB at these frequencies. In addition, the Low Demodulator Golay filter cut-off frequency has been set above 500 kHz (approximately 550 kHz) and the High Demodulator Golay cut-off frequency has been set above 4.0 MHz (approximately 4.2 MHz). Section 3.8 (Low Demodulator) discusses the problems encountered in designing a satisfactory 500 kHz Golay filter. Each Golay filter provides an amplitude response roll-off above cut-off at approximately 120 dB/octave. The amplitude response roll-off at the lower video bandwidths accommodated by each speed is determined by the selected low-pass output filter. These filters provide an amplitude response roll-off of 20 db/octave with 3 db cut-off frequencies at 2.0 MHz, 1.0 MHz, 560 kHz, 250 kHz, 125 kHz, 70 kHz and 25 kHz.

The record FM electronics are comprised of the High Modulator oscillators, mixer and output stage, the Low Modulator oscillators, mixer and output stage and the Record Amplifier. The playback FM electronics are comprised of the Dual Preamplifier, Playback Amplifiers-Combiner, Limiter, and the Low and High Demodulator electronics prior to the Golay filter network. The amplitude response 3 db points for the combined record and playback FM system, except for the Playback Amplifiers, are separated by a sufficient band of frequencies (approximately 100 kHz - 9.0 MHz in the high speed modes and approximately 100 kHz - 1.2 MHz in the low speed modes), with an essentially linear phase response, to have a negligible effect on the playback video bandwidth. The Playback Amplifier low frequency gain has been reduced to compensate for the high frequency losses incurred in the Record/Playback process (See Equalization discussion of Section 3. 6).

The high frequency amplitude response of the Recorder has been optimized for best pulse response. Due to the 120 db/octave amplitude response roll-off of the Golay filters in the High and Low Demodulators the rise time (10-90%) design goal for the 4 MHz high speed playback (R_{THI}) and 500 kHz low speed playback (R_{TLO}) are given by:

$$R_{THI} = \frac{0.45}{4.0} = 0.112 \times 10^{-6} \text{ sec}$$

and

$$R_{TLO} = \frac{0.45}{0.5} = 0.900 \times 10^{-6} \text{ sec}$$

The attained pulse rise times are approximately

$$R_{THI} = 0.13 \times 10^{-6} \text{ sec}$$

and

$$R_{TLO} = 1.0 \times 10^{-6} \text{ sec}$$

The slope of the leading edge of the 4. 0 MHz high playback pulse begins to taper off at approximately 80% of full amplitude, and therefore, the pulse fails to meet the rise time design goal. This is a non-linear phase phenomenon that may be largely attributed to the non ideal phase response of the Playback Amplifier high speed equalization networks (See Equalization discussion of Section 3. 6). The rise time of the 500 kHz low playback pulse is relatively shorter than the high playback pulse due to the superior phase response of the low speed equalization networks. The lower specified video bandwidths that are accommodated within each speed are less affected by the high frequency Record/Playback losses and the Playback Amplifier equalization networks. Therefore, the rise time, fall time and overshoot characteristics of the playback pulses corresponding to these bandwidths more closely approach their theoretical limitations.

4. 1. 1. 2 Low Frequency Characteristics

The Recorder low frequency response extends to DC. This requires low operating point drifts within the direct coupled video portions of the record and playback electronics and a stable FM carrier frequency. Temperature and supply voltage fluctuations are the primary causes of DC drift.

Each electronic module has been operated within a temperature controlled chamber to determine and minimize its temperature induced operating point drifts over the 25°C to 55°C range. It has been noted that the High Modulator carrier frequency drifted 1.0 kHz/°C (Section 3.2) and the Low Modulator 200 Hz/°C (Section 3.3) over this temperature range. The module supply voltages were varied by plus and minus 10% from their nominal values during temperature testing.

The temperature fluctuations at various points within the assembled recorder have been monitored by a thermocouple bridge. The average temperature within the Recorder case stabilizes after a prolonged period (greater than 1 hr.) at approximately 18°C above ambient.

4.1.2 Record/Playback Gain

The composite video input signal may vary between 0.0 and +2.0 Vdc at the 100 ohm or 0.0 and +1.0 Vdc at the 50 ohm Video Input terminals located on the Remote Control Panel. The Video Level Monitor and Adjust panel buffers this input signal such that the amplitude of the signal applied to the Video Input sub-module is independent of the input terminal used.

The Recorder has unity gain at DC. Playback reproduction of a given DC input level is dependent upon the Recorder DC drift characteristics, considered in Section 5.1.1, and DC linearity.

The Recorder DC linearity is dependent upon the DC linearity of the record and playback video electronics, the deviation linearity of the selected modulator (See Sections 3.2 and 3.3) and the linearity of the discriminator curve within the selected demodulator (See Sections 3.8 and 3.9). The DC linearity of the Recorder may be determined from the pre-acceptance test data of Section 5.2.8.

The Recorder has a nominal AC gain of unity. The AC gain is dependent upon the settings of the Playback Amplifier equalization networks since it is affected by the amplitude and phase response of the record and playback FM electronics and the amplitude and phase response of the wideband Record/Playback process. The Recorder AC gain is also dependent upon the amplitude response of the record and playback video electronics, the deviation linearity of the selected modulator and the linearity of the discriminator curve within the selected demodulator. The Recorder AC gain about various average input signal levels is most accurately determined by checking differential gain. The differential gain of the Recorder may be determined from the pre-acceptance test data of section 5.2.11.

4.1.3 Record/ Playback Distortion

Record/ Playback signal distortion is determined by simultaneously recording two randomly selected tone frequencies (f_1 and f_2) within the video band. In playback, the significant harmonic distortion spectral components appear at frequencies given by $2f_1$, $3f_1$, $2f_2$ and $3f_2$; the significant intermodulation distortion components appear at ($f_1 + f_2$) and ($f_1 - f_2$); and the significant spurious components appear at ($f_c - f_m$) and ($2f_c - 2f_m$), where f_c is the average FM carrier frequency.

The harmonic, intermodulation, and spurious distortion components are affected by the same system parameters as the AC gain linearity considered in section 5.1.2. However, the amplitude and phase response of the Wideband Record/Playback process and the Playback Amplifier equalization networks noticeably enhance these distortion components. The harmonic and intermodulation distortion and ($f_c - f_m$)component amplitudes introduced by a "Back-to-Back" bench interconnection of the Video Input, Modulator, Limiter, Demodulator and Video Output modules were more than 30 db below the two desired tone amplitudes for both the high and low speed cases. This is significantly below the amplitudes of these components for the assembled Recorder as noted in the Intermodulation Distortion pre-acceptance test data of section 5.2.10. Modification of the Playback Amplifier equalization networks as prescribed in section 3.6 will improve the correlation between the "back-to-back" and assembled recorder distortion data.

The amplitude of the spurious component ($2f_c - 2f_m$) is approximately the same for the "back-to-back" bench module interconnection as that observed for the assembled recorder in section 5.2.10. This spurious component will fall outside the playback video signal if the lowest High and Low Modulator FM carrier frequency excursions are at least 1.5 times the High and Low demodulator Golay filter cut-off frequencies. The modulator carrier frequencies have not been set sufficiently high to completely avoid this spurious distortion component. This represents a trade-off between the fact that this distortion component does not seriously degrade the playback video signal and selection of higher FM carrier frequencies would reduce the off-tape signal amplitude and, therefore, the playback video signal-to-noise ratio.

4.1.4 Record/ Playback Noise

The Record/Playback noise introduced by the Recorder is determined by measuring the playback video signal-to-noise ratio (SNR) on a peak signal-to-rms noise basis. Both the magnetic tape and the Recorder electronics contribute to the playback video noise level.

Magnetic tape noise is primarily induced by tape surface irregularities. However, this noise for the recommended 3M type 888 tape is masked by the Recorder electronic noise.

The Dual Preamplifier (See Section 3.5) and Playback Amplifier (See Section 3.6) portions of the playback electronics are the primary sources of random electronic noise. The playback video noise level is inversely proportional to the Playback Amplifier output signal-to-noise ratio (SNR). Since the tape noise is masked by the electronic noise, the Playback Amplifier output SNR is proportional to the level of the off-tape video signal. The amplitude of the off-tape signal is sufficiently large to meet the SNR specified for the Recorder. The off-tape signal amplitude for a given instantaneous carrier frequency may be increased in several ways (e.g. increased video head gap width, increased video head gap length, increased video head-to-tape speed) that would require higher video head scanning and longitudinal tape speeds. This would increase system power consumption and the tape volume required for a given record capacity. The video head inductance may be increased to raise the off-tape signal amplitude. However, this would lower the head resonant frequency and more complex compensation would be required in the playback electronics. Several other possibilities for increasing the off-tape signal amplitude are presently being considered. These possibilities include development of a magnetic tape with its oxide particles aligned with the 45 degree video scan, "slanting" of the video heads with respect to the 45 degree scan so that they are aligned with the oxide particles on available tapes, and the use of AC tape erase. Significant random noise sources also include system low frequency operating point drifts (See Low Frequency Response portion of Section 5.1.1), oscillator instabilities within the High and Low Modulators (See Sections 3.2 and 3.3), and video head tracking errors due to variations of the longitudinal tape speed. Random modulation of the FM carrier due to fluctuations of the video headwheel speed does not significantly contribute to the playback video noise level.

Significant sources of hard noise include FM carrier and twice carrier feedthrough into the demodulated video signal, the distortion signal components considered in section 5.1.3, motor switching frequency disturbances, and DC/DC converter switching frequency disturbances.

FM carrier and twice carrier frequency feedthrough to the playback video signal are minimized by conservative power supply decoupling, careful grounding, and separation of the FM and video wires in the electronic nest and within the High and Low Demodulator modules. Due to the higher frequencies involved, this hard noise feedthrough component is more difficult to control in the HIGH PLAYBACK mode of system operation.

The motor switching frequency disturbances (2ϕ 400 Hz & 2ϕ 100 Hz) have been minimized by reducing the fluctuations in total current through the motor by careful control of the motor driven switching waveforms and by separately decoupling each driver from the +28 Vdc supply. In addition, the motor driver assembly is shielded from the electronic nest, and the shielded motor winding leads are routed away from the video heads and Dual Preamplifier.

The DC/DC Converter switching frequency (80 kHz - 100 kHz) disturbances have been minimized by filtering the converter output leads, by shielding the converter, and by conservative power supply decoupling and careful grounding throughout the Recorder. A considerable amount of time was spent determining the optimum grounding techniques for various portions of the electronic system.

4.2 SPECIAL COMPONENT EVALUATION TESTS

4.2.1 Rotary Transformer

To accomplish the transfer of signal between the rotating headwheel and the remainder of the system, a rotary transformer was developed to replace the conventional slip ring configuration. In this transformer, the signals are transferred by inductive coupling between rotating and stationary ferrite cores. Because of this, no physical contact is required and the wear problem associated with slip rings is eliminated. Other advantages are the insusceptibility to vibration disturbances, decreased cross-talk between channels (15 db better than slip rings), easier assembly, and higher reliability. For these reasons the rotary transformer scheme was best suited for this system.

The design of this transformer was constrained by the established head inductance (22 μh), head-to-preamp gain, and geometrical considerations. The input inductance to the transformer was established at 220 μh as a compromise between low i^2R losses and desirable ratio of head inductance to transformer inductance. Further compromise had to be made between minimum use of ferrite material and minimum reluctance of the air gap. This gap was established at .002 inch because of vibration considerations. "Ferrite MN31" from General Precision and "Mumetal" were chosen because of magnetic properties for the core material and shielding respectively. These developments led to the final configuration which was performance evaluated primarily on the basis of system performance. With respect to the standard slip ring configuration employed in the breadboard, the only degradation noticed was a 1 to 2 db loss in S/N during playback at the 0.5 MHz bandwidth. This, of course, was considered as a worthy trade-off for the significant enhancement in reliability.

4.2.2 Magnetic Tape

Various magnetic tapes were evaluated during the development program. Initially, 3M591 tape was employed in the breadboard transport. This tape performed well but was subsequently replaced by 3M888. Tests with the 3M888 yielded equivalent performance and the tape exhibited a lesser flaking tendency. The balance of the tapes tested were experimental RCA and 3M samples. None of these tapes exhibited combined performance and wear characteristics as good as the 3M888. Attempts were made to obtain the 888 tape with a 45° oxide orientation which would optimize the tape output for this recording system. These attempts were unsuccessful, but 45° samples were prepared by the RCA laboratories which permitted a comparative evaluation. The RCA sample, with longitudinal orientation as in the 888, yielded a system output noise of 28 mV rms. The RCA sample with the 45° right-hand orientation yielded a system output noise of 18 mV rms. Since these tests were run, the system noise has been reduced considerably so that a rerun might not yield such dramatic results. However this is an area which should be pursued.

4.2.3 Erase Head

The erase head is energized in the Record modes to erase all previously recorded information. The head incorporates a 0.001 inch gap which spans the full width of the tape. The magnetic path is completed through highly permeable Carpenter #49 steel pole pieces, and a thin beryllium copper back gap spacer. The DC resistance of the erase head is 240 ohms, and approximately 25 ma of current is required to effect complete tape erasure.

Two erase head designs were evaluated for use in the recorder. The first design was prompted by minimum power considerations, and evolved as a 93 ohm head which required approximately 30 ma of DC current to effect complete tape erasure. This design worked well, but exhibited an objectionably high remanence which tended to partially erase the tape signal in rewind and playback. This effect could not be tolerated and, as a result, a new design was conceived. In this design the thickness of the back gap spacer was doubled to increase the effective reluctance of the magnetic path. The new head exhibited a reduced intrinsic remanence as a result, but required additional turns to duplicate the required fringing flux. This final erase head design had a DC resistance of approximately 240 ohms and required 25 ma of current to completely erase the tape.

5.0 PRE-ACCEPTANCE TESTS

A summary of the performance test results obtained in the Pre-Acceptance tests is included in the following.

5.1 VOLUME

The volume of the recorder was computed from lineal measurements of length, width and height.

Volume = 10 X 14 X 6.1 = 854 $in.^3$

5.2 WEIGHT

The weight of the recorder proper, less interconnecting cables and auxiliary controller, was measured using a laboratory scale.

Weight = 30.0 lbs.

5.3 POWER DISSIPATION

The surge and quiescent input power to the recorder was measured at an input voltage of +28.0 volts for each of the selectable modes of operation. The following table gives the results of the quiescent power measurements. The starting surge power requirements were recorded by means of a Visicorder and the results are summarized in Figures 5-1, 5-2, 5-3, 5-4 and 5-5.

TABLE 5-1. POWER DISSIPATION

Mode	Current (Amps)	Power (Watts)
STOP	0.38	10.6
LOW SPEED RECORD	1.45	40.6
LOW SPEED PLAYBACK	1.6	44.8
HIGH SPEED PLAYBACK	1.95	54.6
HIGH SPEED RECORD	1.85	51.8
REWIND	1.15	32.2

5.4 POWER REQUIREMENTS

The recorder incorporates regulator circuitry which limits the input power voltage level to +22.5 volts prior to distribution. With the recorder in a run mode, the voltage

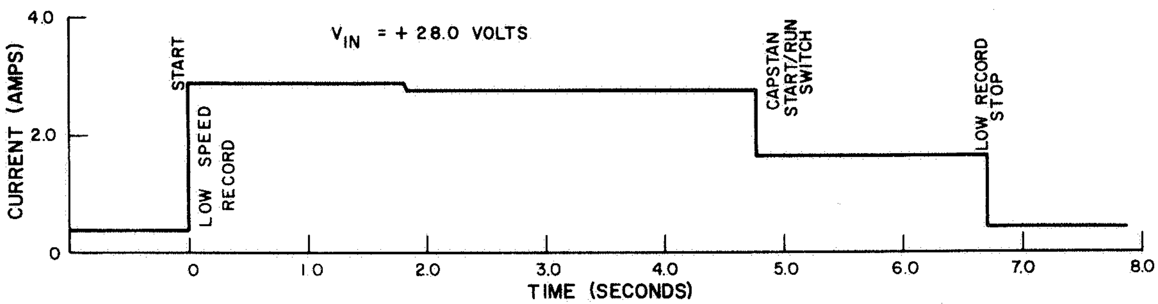


Figure 5-1. Input Current vs Time for Low Speed Record

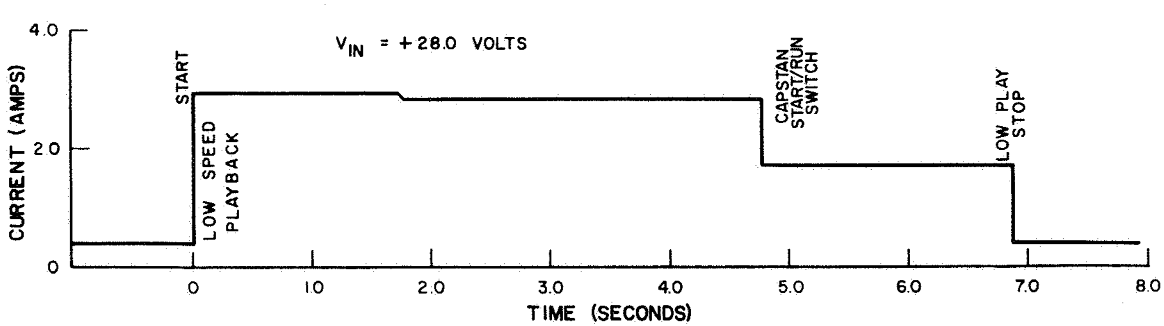


Figure 5-2. Input Current vs Time for Low Speed Playback

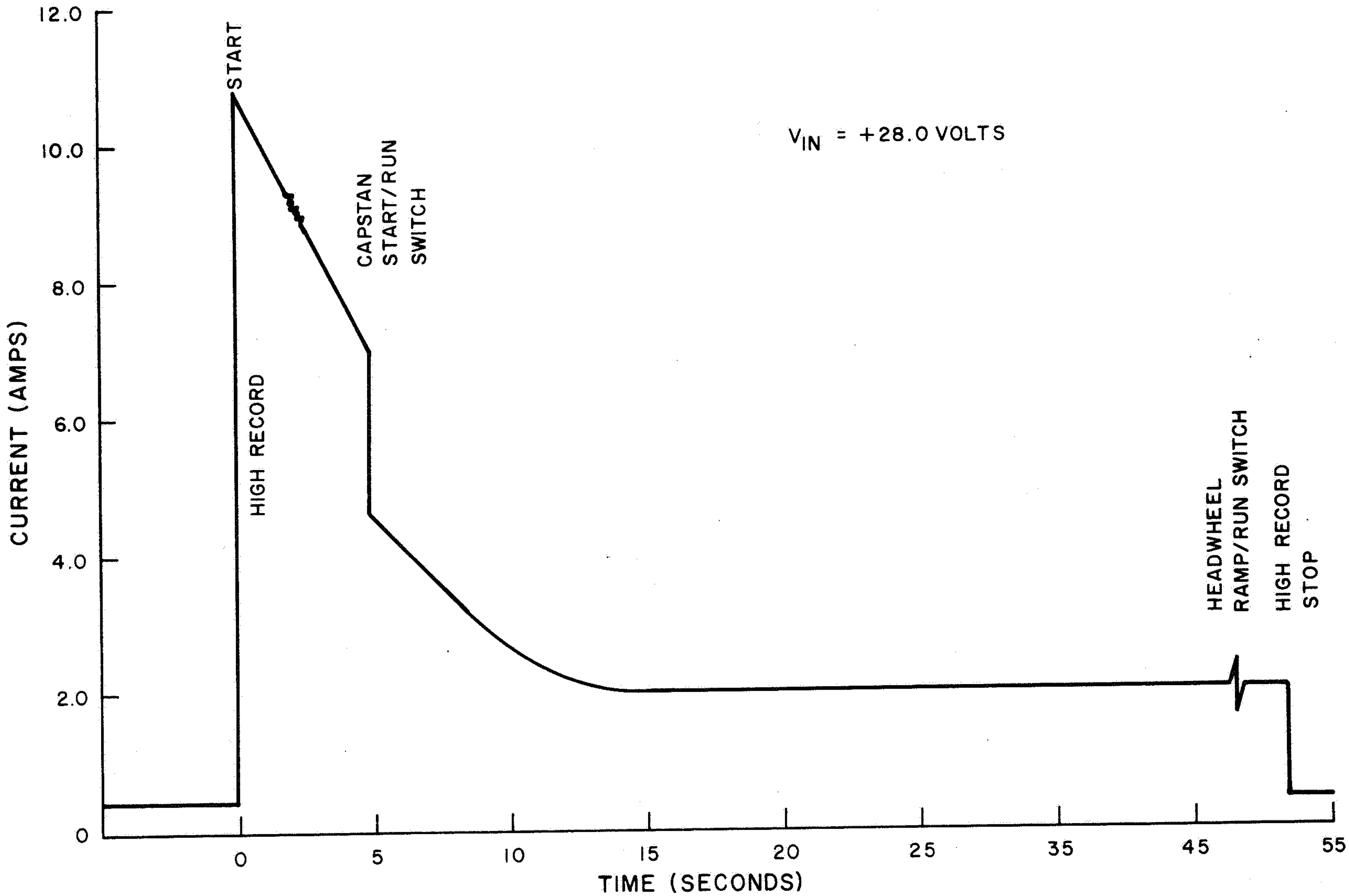


Figure 5-3. Input Current vs Time for High Speed Record

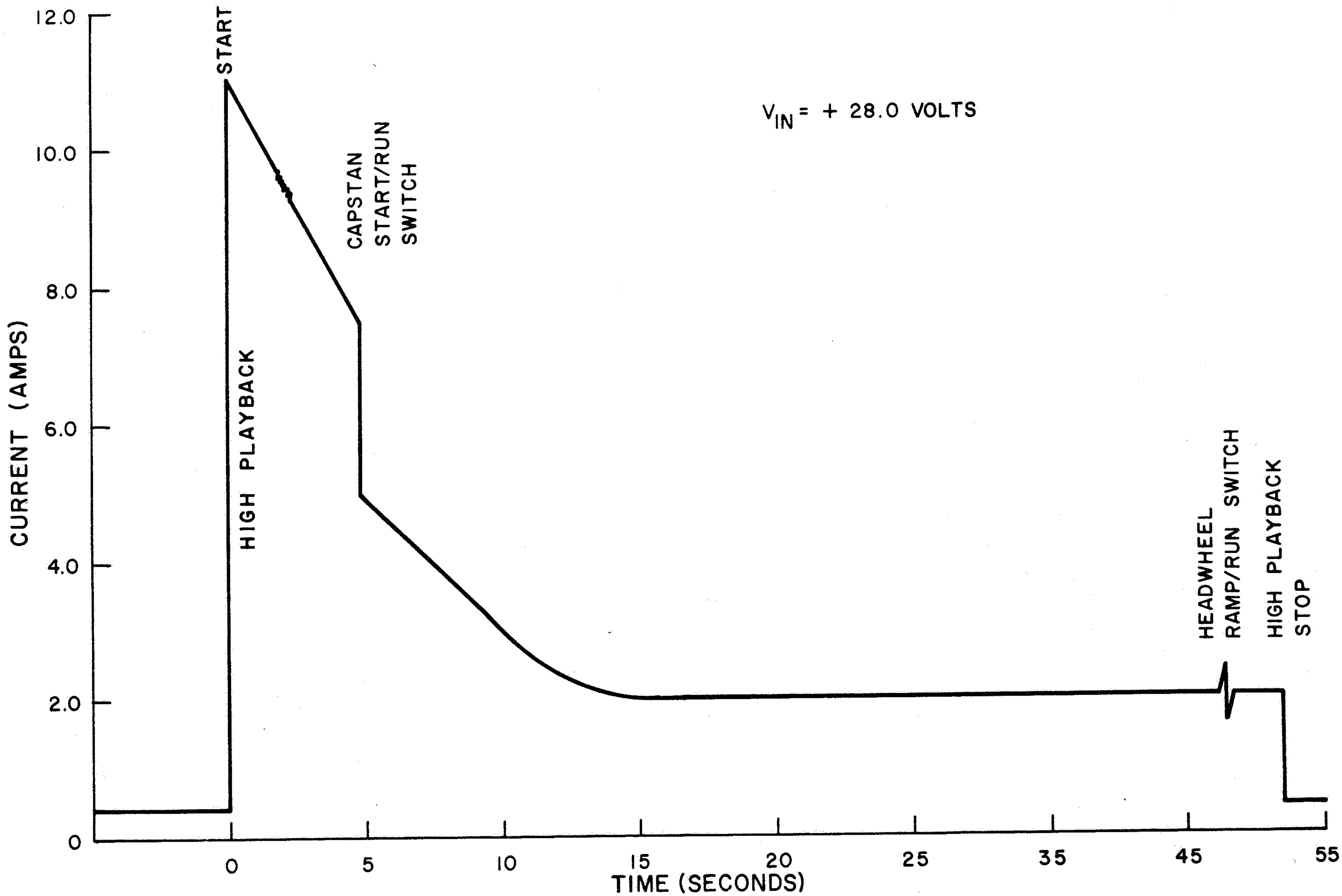


Figure 5-4. Input Current vs Time for High Speed Playback

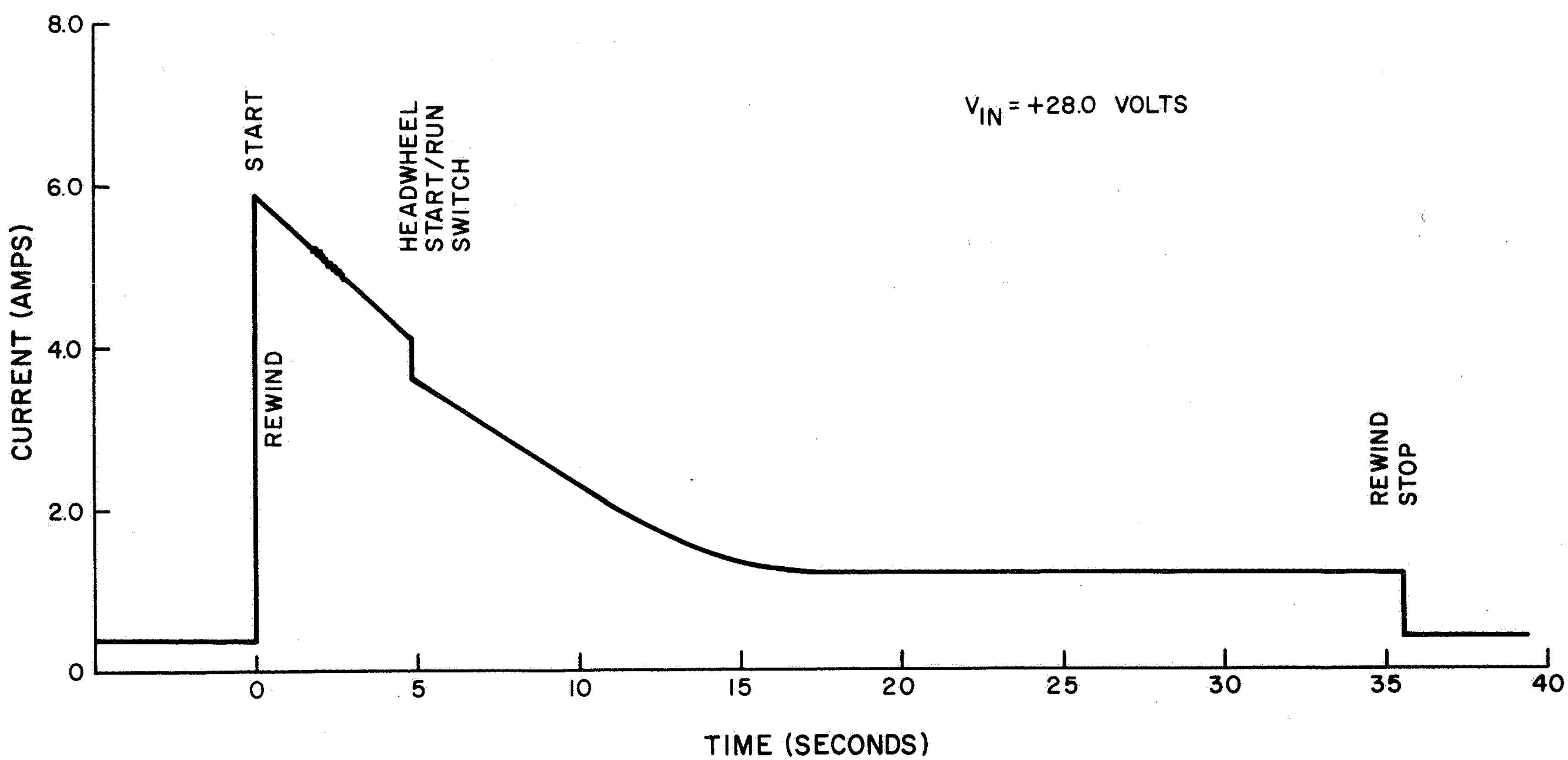


Figure 5-5. Input Current vs Time for Rewind

was reduced to 24 and raised to 32, demonstrating compliance with the requirement that it be insensitive to ± 4 volt DC variations of the incoming supply voltage about the nominal +28 volt level.

5.5 TRANSIENT VOLTAGES

The recorder incorporates transient suppression circuitry which reduces power line transients to a safe level before distribution. Spikes with amplitude and duration of +78 volts for 10 microseconds at 10 pps, and -100 volts for 10 microseconds at 10 pps, were superimposed on the recorder in various run modes. It was verified than no damage nor degradation in performance had occurred to the recorder in the presence of spikes.

5.6 RIPPLE

The recorder incorporates filtering circuitry to squelch ripple on the incoming power lines. The effectiveness of this filtering was demonstrated by injecting 1 volt peak-to-peak random 50-20,000 Hz noise on the input power supply line and recording, in the high speed record mode, a standard TV monoscope test pattern signal with one volt peak white amplitude. Rewinding the tape to the beginning of the recorded segment, and, without removing the ripple generator, the recorder was then cycled to the high speed playback mode of operation. The output signal in playback was observed on an RCA TR-22 (domestic) TV monitor, and no picture degradation was noticed.

5.7 LOW LINE LIMITS

The recorder incorporates protective circuits that will switch it safely into Recorder-Off, in the event that the input supply voltage falls to 20 volts. The recorder will then remain in Recorder-Off until the input supply is restored to at least +24 volts, and the Recorder-On command is re-initiated. When this occurs, the recorder will turn-on and cycle to the mode of operation indicated by the mode selector switch on the auxiliary controller. This protective feature was demonstrated by cycling the recorder to all of the selectable modes of operation. In each mode the supply voltage was reduced to +20 volts and the switch to Recorder-Off observed. The input voltage was then restored to the nominal +28 volt level, the Recorder-On command re-initiated and operation in the selected mode was observed.

5.8 DC LINEARITY

DC voltage levels were applied to the video input jacks of the recorder and segmented recordings were made in the high speed mode. The DC levels were selected to cover the entire dynamic range of the 50 ohm input termination. The recorded signal was then played back in the High-Playback and Low-Playback modes and the results are shown in Table 5-2.

When reproducing the recorded levels, the recorder's 70 kHz output filter was employed for noise suppression. Measurement of $V_{out}-V_{in}$ was made directly for each recorded level using a HP Model 413A DC null voltmeter.

A linearity analysis for the high and low speed modes may be made from the $V_{out}-V_{in}$ vs. V_{in} plots as shown in Figures 5-6 and 5-7, since this relationship is a linear function of the slope of the true input/output transfer characteristic.

TABLE 5-2. DC LINEARITY MEASUREMENT

High Record DC Level (Volts)	High PB (Volts)	Low PB (Volts)
-0.5	-0.475	-0.51
-0.4	-0.43	-0.38
0	-0.035	0
+0.5	+0.45	0.49
+0.8	+0.75	0.75
+1.0	+0.96	0.94

5.9 SIGNAL-TO-NOISE

The recorder was cycled to the High Record mode and a recording made of the undeviated carrier at 0 volts input. Segmented recordings were also made at selected DC voltage input levels to cover the entire dynamic range of the 50 ohm video input termination. This recording was then reproduced in both High and Low playback modes and the RMS noise level monitored at the 50 ohm output termination with a HP 3400A wideband true RMS voltmeter. The measurements were taken initially with no output filter in the High and Low playback modes. Data was then taken with the 560 kHz filter in the High playback mode to demonstrate the improved S/N obtainable. Results are given in Table 5-3. The signal to noise requirement for 35 db (peak-to-peak)/(RMS noise) minimum was demonstrated.

5.10 INTERMODULATION DISTORTION

Recordings were made in the High Record and Low Record modes as shown using the video 50 ohm input termination. The recordings were then played back and the IM distortion was measured at the 50 ohm video output termination using a Singer model SPA-3/25a spectrum analyzer.

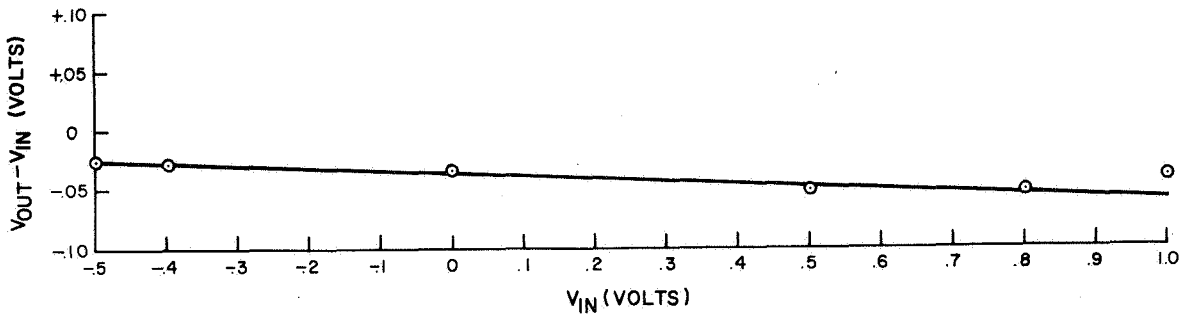


Figure 5-6. DC Linearity, High Record-High Playback

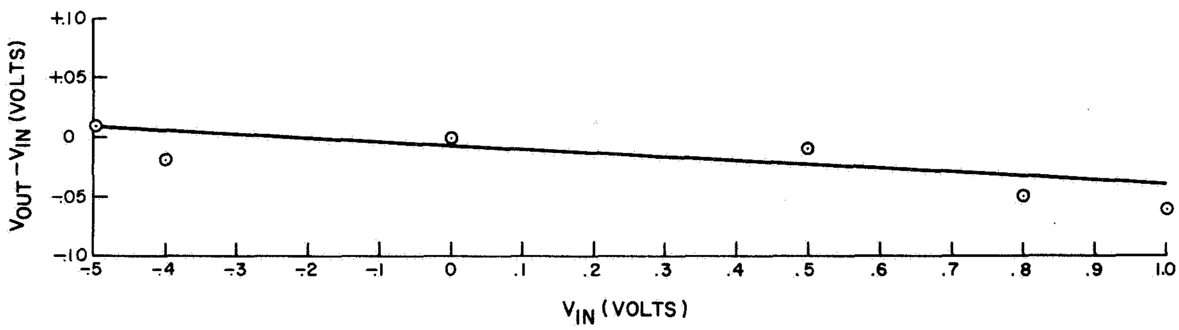


Figure 5-7. DC Linearity, High Record-Low Playback

TABLE 5-3. SIGNAL-TO-NOISE MEASUREMENTS

High Record DC Level (Volts)	High Playback DC Level (Volts)	High Playback RMS Noise (MV) No Filter	High Playback RMS Noise (MV) 560KC Filter	Low Playback DC Level (Volts)	Low Playback RMS Noise (MV) No Filter
-0.5	-0.475	9.5	4.6	-0.51	30.0
-0.4	-0.43	11.8	5.8	-0.38	18.5
0	-0.035	17.8	3.5	0	16.5
+0.5	+0.45	19.0	4.2	0.49	17.0
+0.8	+0.75	20.0	5.0	0.75	18.0
+1.0	+0.96	25.0	5.4	0.94	19.0

5.10.1 Intermodulation Products, High Record - High Playback

f_1 = 4MHz, 0.5 Volt Peak-to-Peak

f_2 = 1MHz, 0.5 Volt Peak-to-Peak

Input to recorder biased to +0.5 volt DC level. The maximum input swing to the recorder shall then be from 0 to +1.0 volt from the worst case amplitude (i.e., when f_1 and f_2 amplitudes wholly reinforce each other). Results are given in Table 5-4.

TABLE 5-4. INTERMODULATION PRODUCTS, HIGH RECORD-HIGH PLAYBACK

Signal	Record	Playback
f_1 (4MC)	0db	-5db
f_2 (1MC)	-2db	-2db
f_1-f_2 (3MC)		-22db
f_c-f_1 (2.25MC)		-16db
$2f_2$ (2MC)		-27db

5.10.2 Spurious Products, High Record - High Playback

f_1 = 4MHz, 1.0 Volt Peak-to-Peak

Input to recorder biased to +0.5 volt DC level. The maximum input swing to the recorder shall then be from 0 to +1.0 volt. See Table 5-5.

TABLE 5-5. SPURIOUS PRODUCTS, HIGH RECORD - HIGH PLAYBACK

Signal	Record	Playback
f_1 (4MC)	+6db	0db
f_c-f_1 (2.25MC)		-12db
$2f_1-f_c$ (1.75MC)		-28db

5.10.3 Intermodulation Products, Low Record - Low Playback

f_1 = 500kHz, 0.5 volt Peak-to-Peak

f_2 = 100kHz, 0.5 volt Peak-to-Peak

Input to recorder biased to +0.5 volt DC level. The maximum input swing to the recorder shall then be from 0 to +1.0 volt for the worst case amplitude (i.e., when f_1 and f_2 amplitudes wholly reinforce each other). See Table 5-6.

TABLE 5-6. INTERMODULATION PRODUCTS, LOW RECORD - LOW PLAYBACK

Signal	Record	Playback
f_1 (500KC)	0db	-2db
f_2 (100KC)	-2db	0db
f_1-f_2 (600KC)		-32db
f_1-f_2 (400KC)		-25db
f_c-f_1 (280KC)		-30db

5.10.4 Spurious Products, Low Record - Low Playback

f_1 = 500kHz, 1.0 volt Peak-to-Peak

Input to recorder biased to +0.5 volt DC level. The maximum input swing to the recorder shall then be from 0 to +1.0 volt. See Table 5-7.

TABLE 5-7. SPURIOUS PRODUCTS, LOW RECORD - LOW PLAYBACK

Signal	Record	Playback
f_1 (500KC)	+2db	0db
$2f_c-2f_1$ (560KC)		-22db
f_c-f_1 (280KC)		-28db

5.11 DIFFERENTIAL GAIN

This test was performed for the High Speed Record to High Speed Playback and High Speed Record to Low Speed Playback modes of operation, using the 50 ohm input/output signal terminations. A 0.2 volt peak-to-peak sinewave at 3.5 megahertz was superimposed on the following DC levels:

-0.3 volts (For demonstration only)

-0.2 volts (For demonstration only)

+0.1 volts

+0.3 volts

+0.7 volts

+0.9 volts

Each of these signals was recorded for one minute and, upon reproduction, the output of the recorder was coupled to the input of a Rhode and Schwartz type USVH Selective microvoltmeter. The average 3.5 megacycle signal amplitude was measured and recorded for each section in High Speed Playback and Low Speed Playback.

5.11.1 Record High - Playback High

Differential gain measurements are given in Table 5-8.

TABLE 5-8. DIFFERENTIAL GAIN MEASUREMENTS, HIGH RECORD - HIGH PLAYBACK

Record High		Playback High	
3.5 MC VAC (P/P) Volts	VDC Volts	VDC Volts	3.5 VAC (RMS) Millivolts
0.2	-0.3	-0.32	45
0.2	-0.2	-0.22	45
0.2	+0.1	+0.15	44
0.2	+0.3	+0.32	45
0.2	+0.7	+0.68	43
0.2	+0.9	+0.87	44

Based on the measurements in the table:

$$\text{Diff. Gain} = \frac{\text{V max} - \text{V min}}{\text{V min}} \text{ X } 100$$

$$= \frac{45 - 43}{43} \text{ X } 100$$

$$= 4.6\%$$

5.11.2 Record High - Playback Low

Differential gain measurements in the mode are as shown in Table 5-9.

TABLE 5-9. DIFFERENTIAL GAIN MEASUREMENTS, HIGH RECORD - LOW PLAYBACK

Record High		Playback Low	
3.5 MC VAC (P/P)	VDC (Volts)	VDC (Volts)	3 5/8 MC VAC (RMS) Millivolts
0.2	-0.3	-0.33	56.5
0.2	-0.2	-0.23	58.0
0.2	0	-0.05	60.0
0.2	+0.1	+0.09	62.0
0.2	+0.3	+0.28	62.0
0.2	+0.7	+0.65	62.5
0.2	+0.9	+0.83	63.6

These data produce the following:

$$\text{Diff. Gain} = \frac{62.5 - 60.0}{60.0} \text{ X } 100$$

$$= 5.8\%$$

5.12 BANDWIDTH

A 100 nanosecond rise time pulse, 10 microseconds wide, was recorded and upon reproduction the rise time at the 10% to 90% points was measured. The design goal for the rise time is:

$$R_t = \frac{0.45}{BW}$$

The Measured R_t = $0.2 \text{ X } 10^{-6}$ sec. @ high speed

R_t = $1.15 \text{ X } 10^{-6}$ sec. @ low speed

5.13 FILTERS

The curves shown in Figures 5-8, 5-9 and 5-10 show the characteristics of the Input, Golay Output Filter, and Recorder Output Filters, respectively.

5.14 HORIZONTAL STABILITY

A standard monoscope test pattern signal having a one-volt peak white level was applied to the 50 ohm video input termination and recorded in High Speed Record mode. The reproduced signal was fed to an RCA type TR-22 TV monitor having a 6" X 8" raster. Compliance with the requirements that the maximum horizontal deviation of either picture edge of the display not exceed ± 1/16 inch was met. (Measured variation, less than 1/32 inch).

5.15 TIME BASE STABILITY

This test was performed as a basis of evaluation of the design goal objective to meet Federal Communications Commission standards, Section 3-3. 687 (a) paragraphs 7 and 8. A III model PG-2 pulse generator was triggered from a stable 1 MHz crystal source divided down to 12.5 kHz. The output of the pulse generator, consisting of a train of one volt peak positive pulses 5 μsec wide, was applied to the 50 ohm video

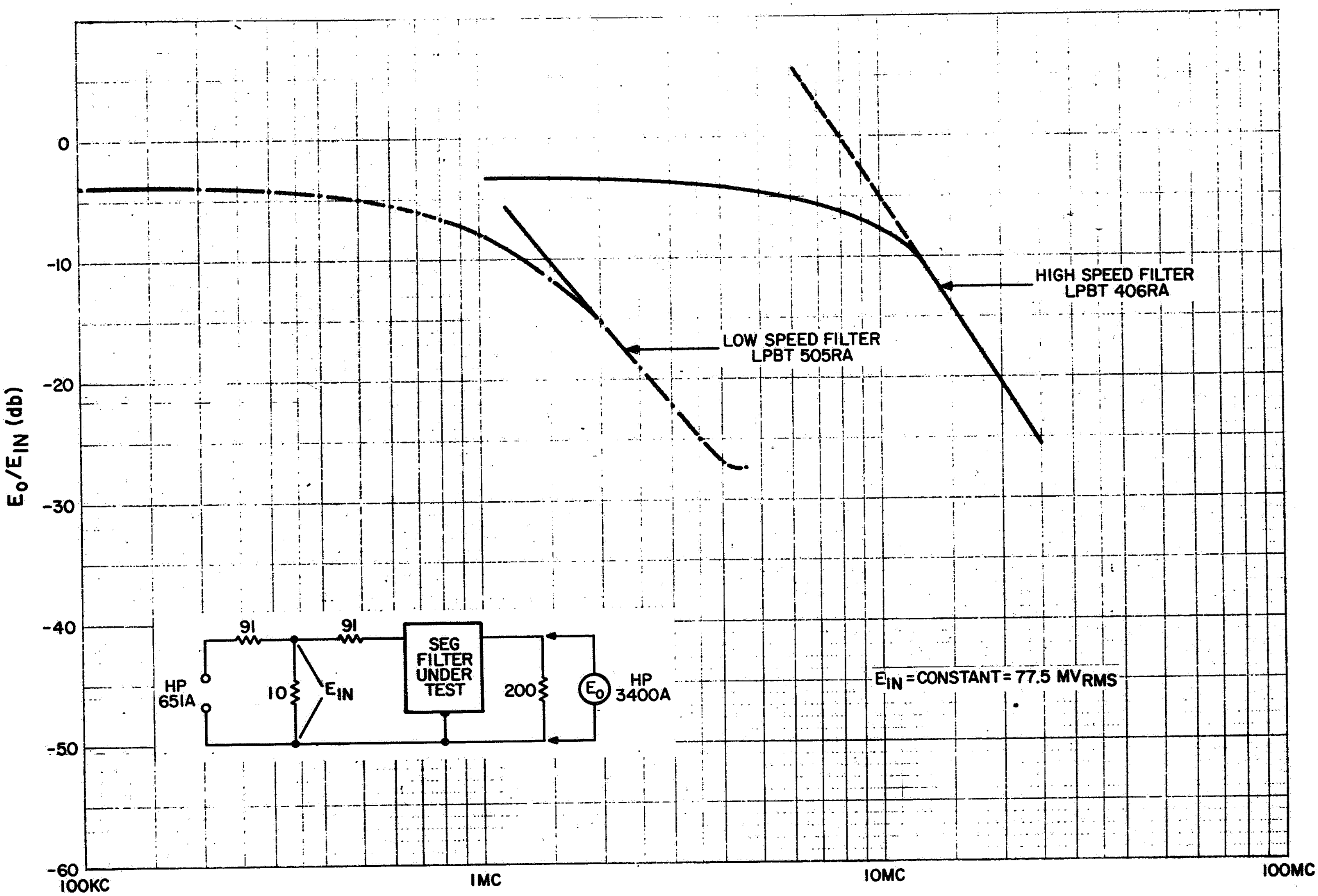


Figure 5-8. Input Filter Response Curves

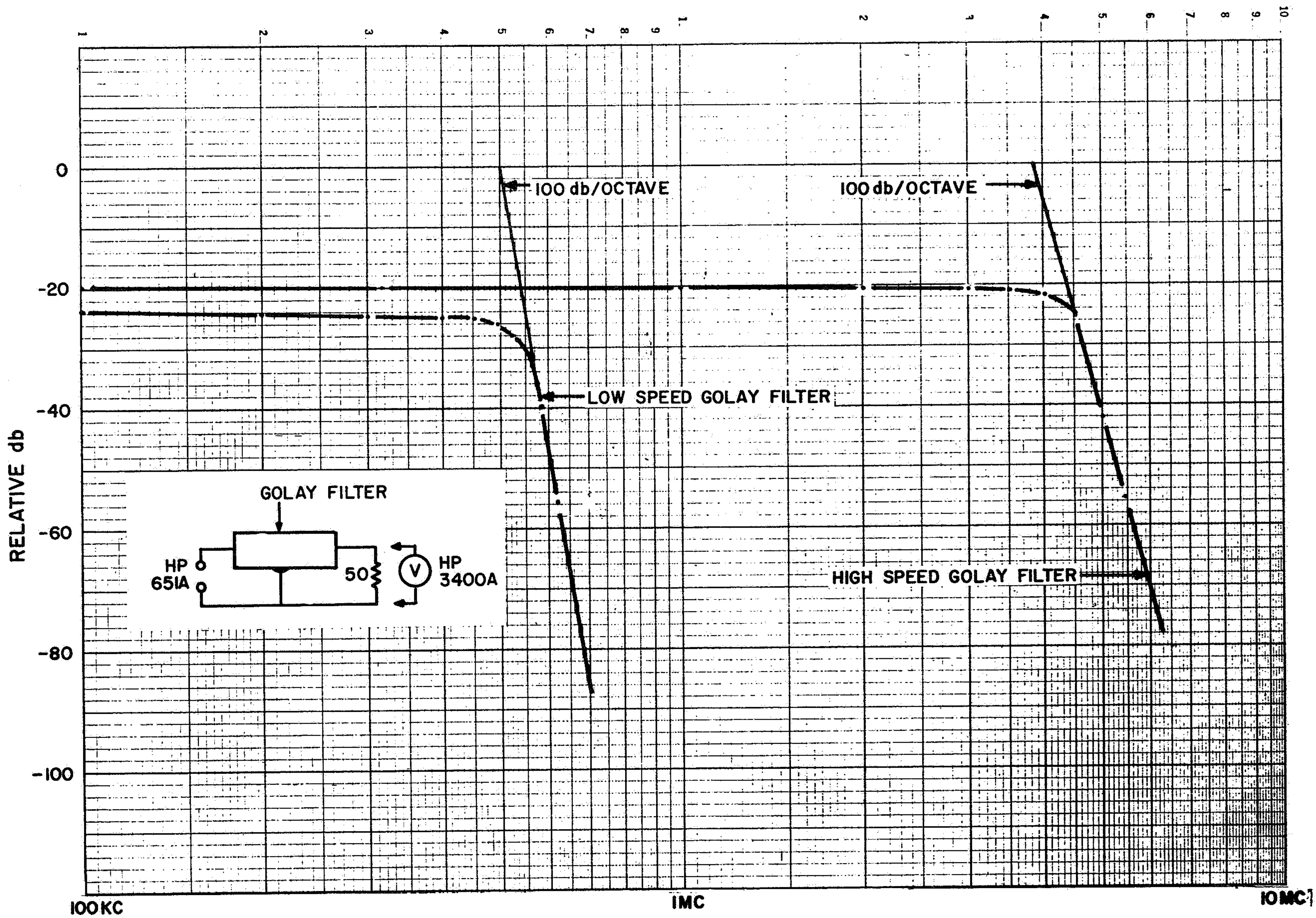


Figure 5-9. Golay Output Filter Response Curves

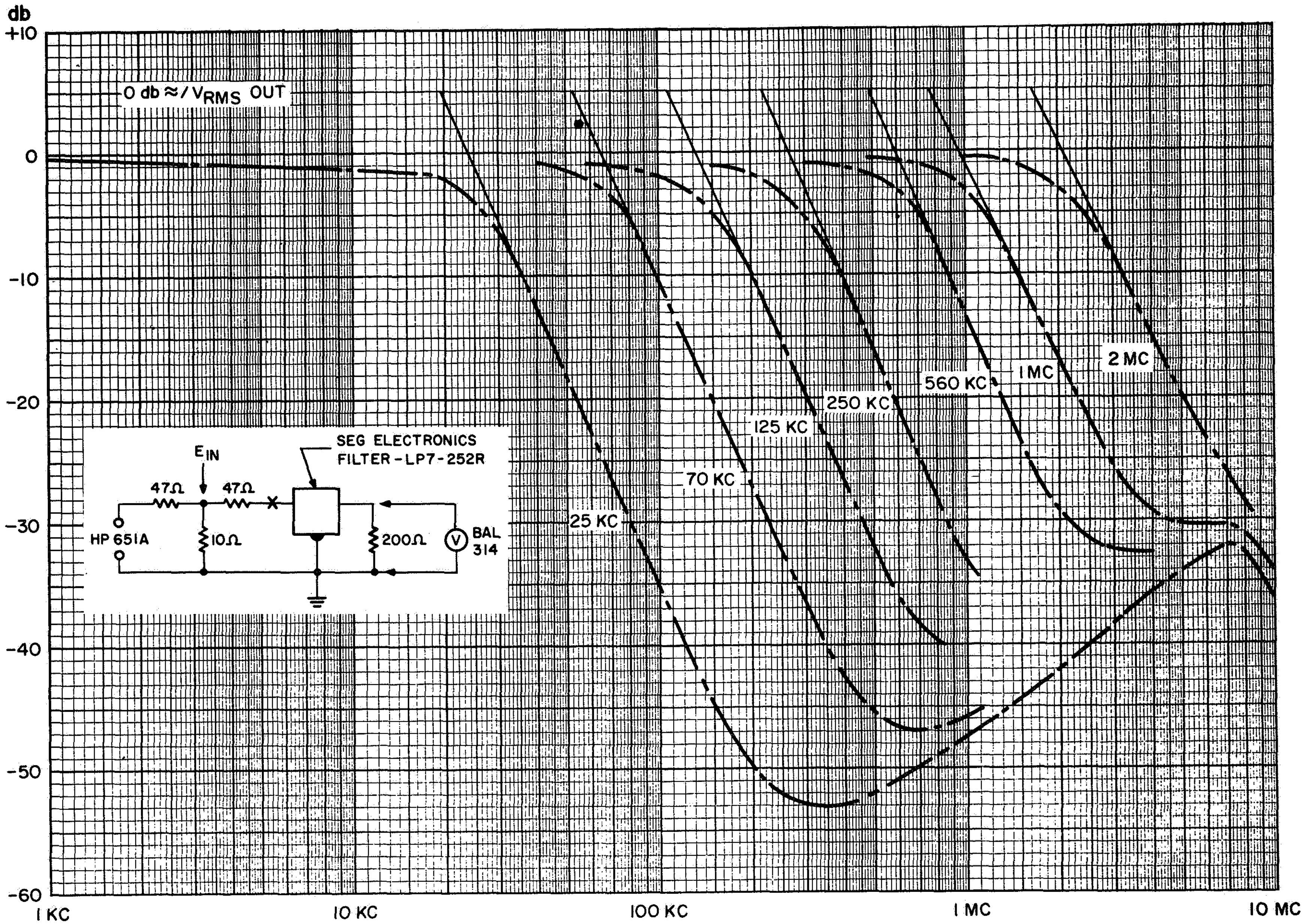


Figure 5-10. Output Filter Response Curves

input jack of the controller. The recorder was cycled to the High Speed Record mode of operation and a 10 minute recording made. The reproduced output of the recorder was then applied to a custom built time base jitter detector. The jitter detector compared the phase of the recorder output pulse train to that of the same pulse train delayed for a given period (t_d) and generated an output signal with a level proportional to the amplitude of jitter and a frequency at the jitter rate. A Honeywell model 906-c Visicorder was used to calibrate and make a permanent record of the test results. Results of the tests in the High Speed mode are shown in Figures 5-11 and 5-12. The procedure just described was repeated in the Low Record/Low Playback modes of operation. The results of these tests are shown in Figures 5-13 and 5-14.

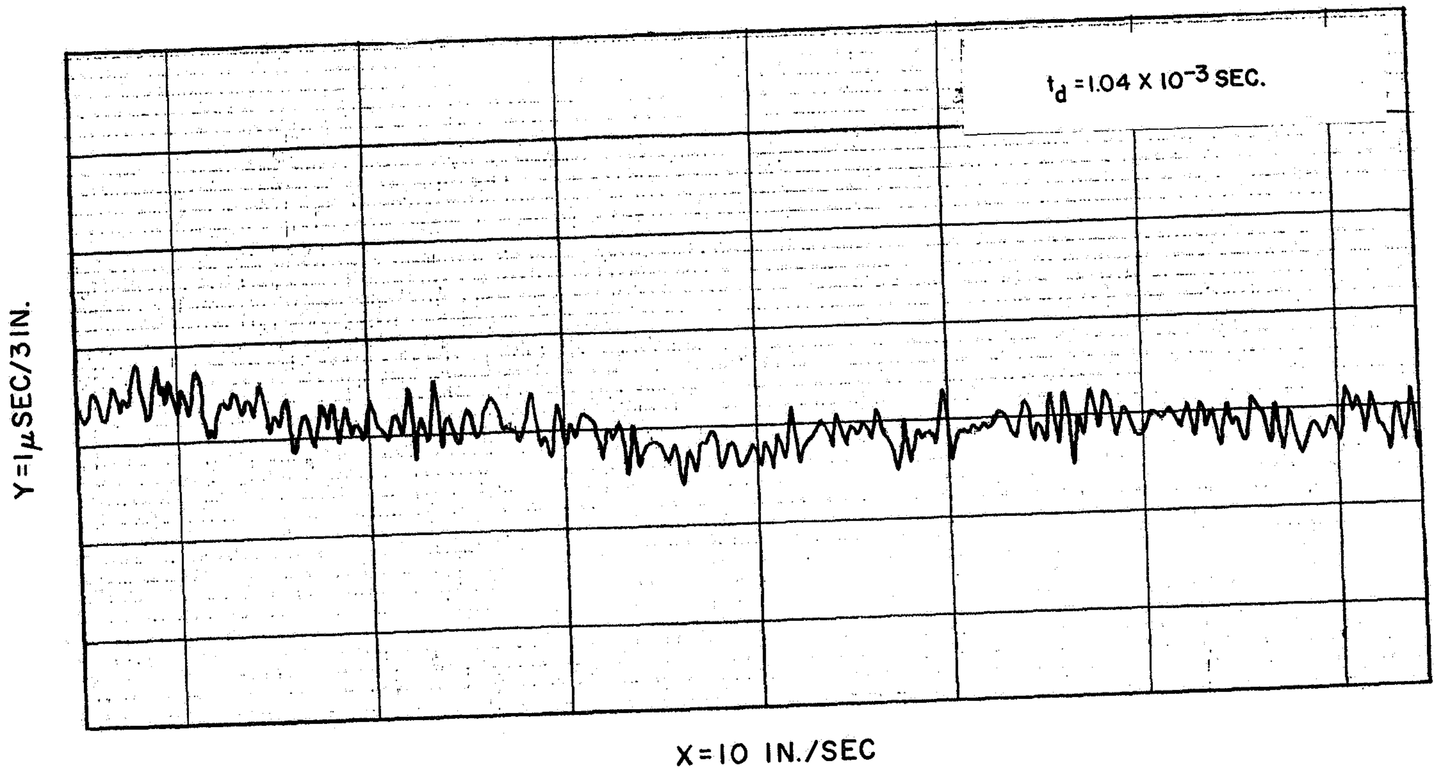


Figure 5-11. Time Stability, High Record/High Playback

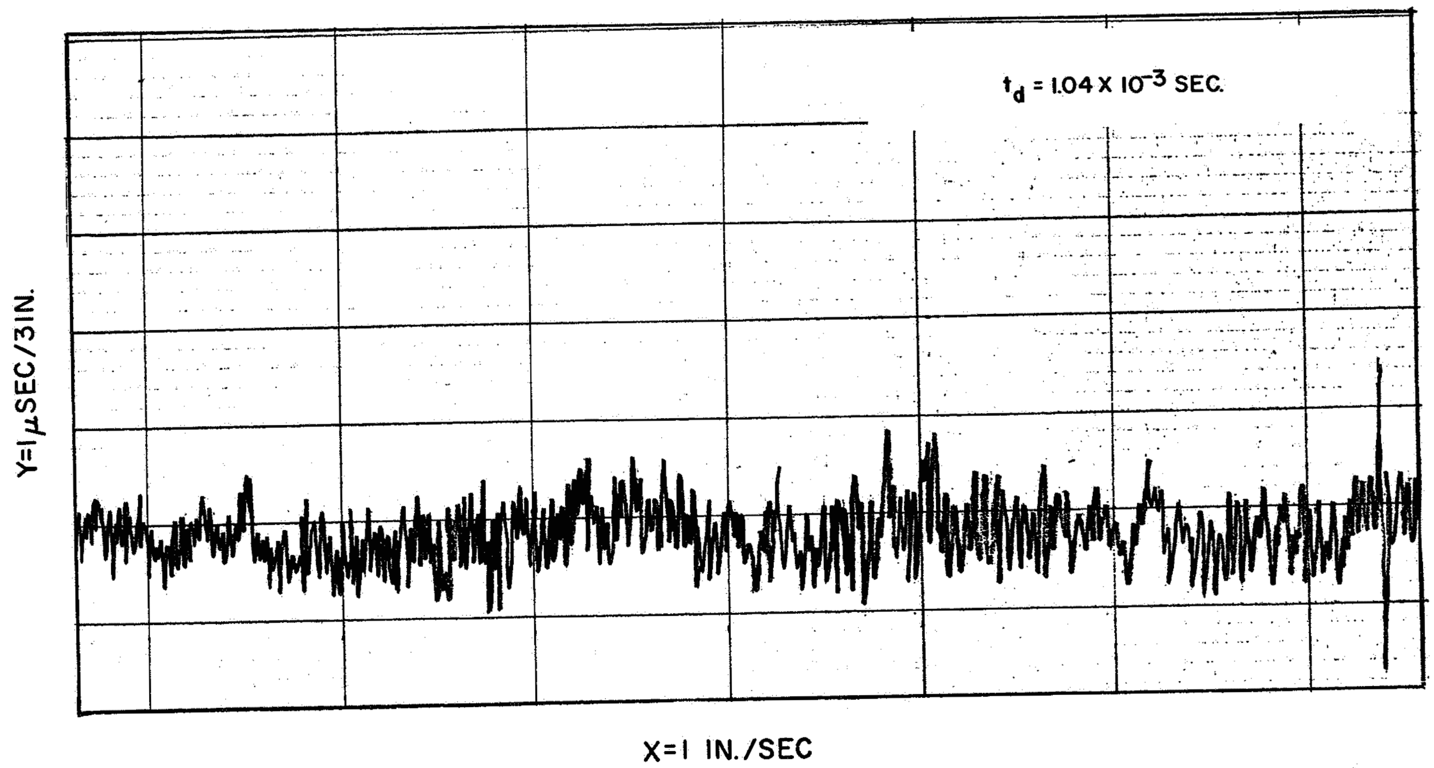


Figure 5-12. Time Stability, High Record/High Playback

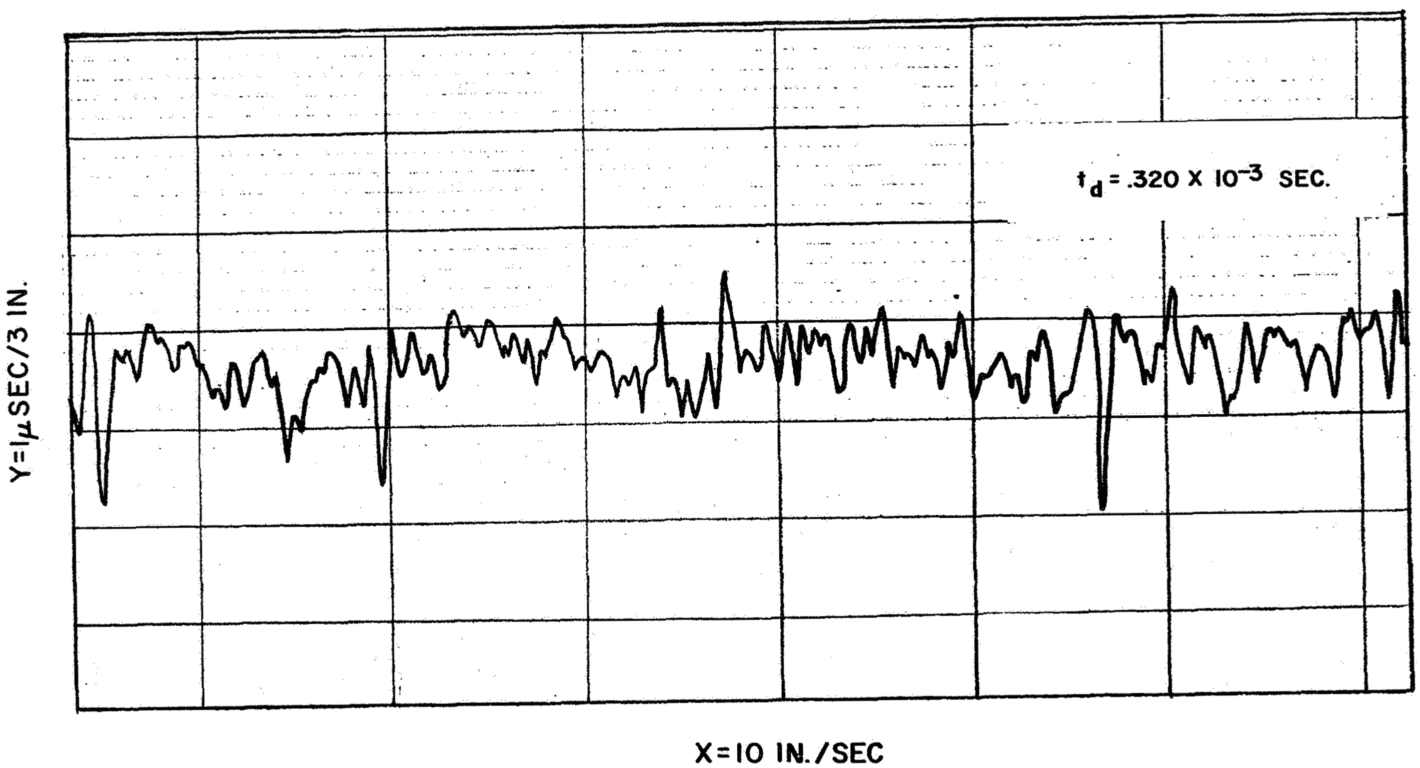


Figure 5-13. Time Stability, Low Record/Low Playback

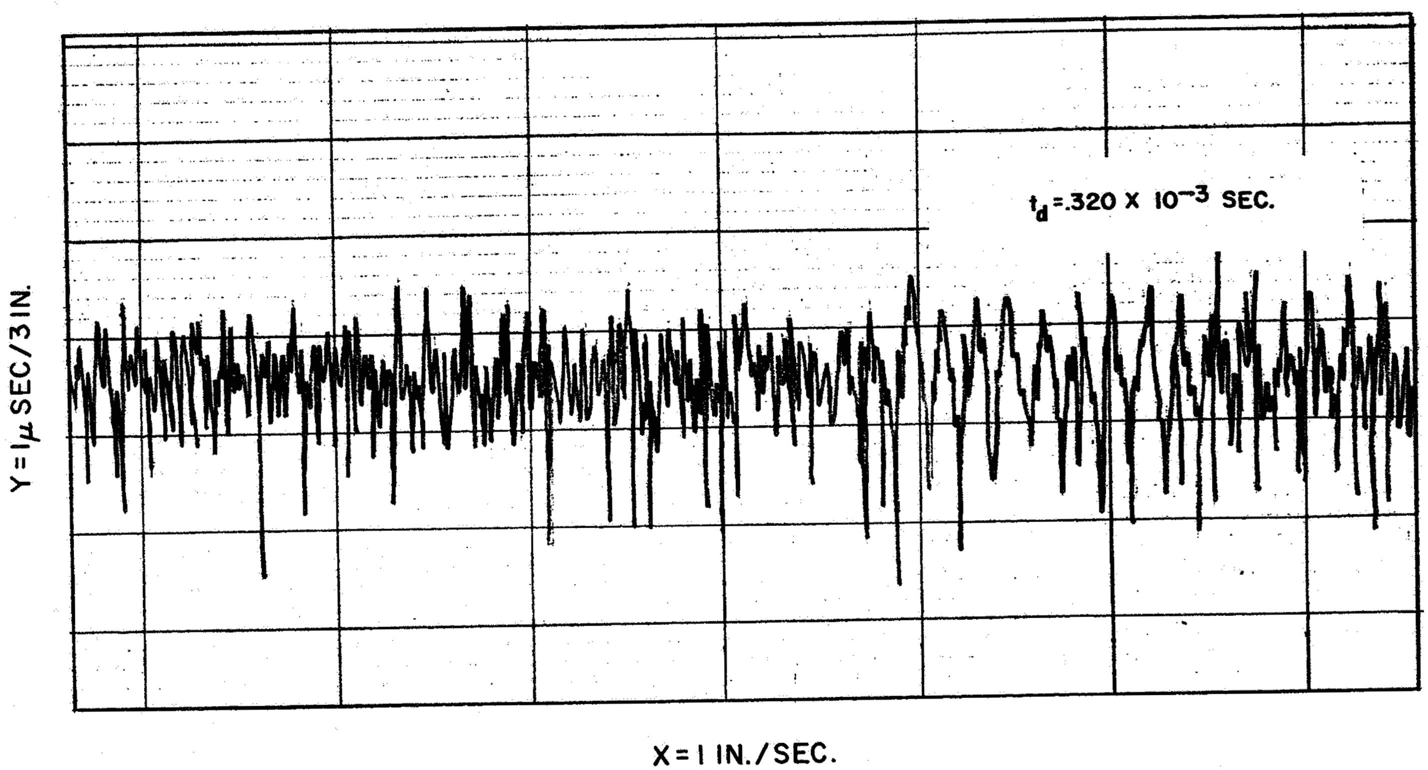


Figure 5-14. Time Stability, Low Record/Low Playback

6.0 EXTENSION OF CAPABILITY

In the course of the development contract many questions have arisen relating to variations or extensions of the capability of the equipment. These considerations are included in the following.

6.1 WEIGHT REDUCTION

The weight of the equipment could be reduced by 2 or 3 pounds without loss of capability if a formal weight reduction program were undertaken.

The weight could be reduced an additional 3/4 lbs. by removal of the seven selectable output filters, the selection switch and the video adjust meter.

6.2 RECORD TIME

The recorder reeling system was initially designed to accommodate four negator springs for tape tensioning. Early tests demonstrated that sufficient tension could be attained with only two of the springs. Hence, the present reeling system could be readily extended to accommodate sufficient tape for one hour of recording time at the 4 MHz bandwidth. This would simply entail a slight shift in the center of the reeling system, incorporation of reels with an increased outside diameter, and enlargement of the recorder to 11" x 15" x 6.1".

6.3 START/STOP TIME

The equipment as delivered required approximately 50 seconds to attain the speeds associated with the 4 MHz bandwidth and about 5 seconds for the 0.5 MHz bandwidth. The critical element in all modes is the headwheel, since the tape attains speed in less than two seconds. To abbreviate the starting time it would be necessary to incorporate a standby mode which would permit the headwheel to rotate without tape motion. Reliable implementation of this mode entails means to lift the tape from contact with the headwheel when the tape is stationary; otherwise tape damage or head gunking may result. Such a device is now being developed at RCA, and tests have been run to establish the start/stop performance that will be provided when this device is incorporated. The tests were run for the 4 MHz bandwidth only and consisted of a cycling of the power to the capstan (tape drive) while the balance of the recorder elements were maintained in the record mode. Ten cycles were performed in which the capstan was energized for 15 seconds and de-energized for 15 seconds of each cycle. Continuous playback of these 10 cycles yielded 13 seconds of good monitor display for each 15 seconds of power on, indicating a combined record-start, playback-lock-up time 2 seconds. Each cycle consumed 16 seconds of playback time indicating that the tape stop time is longer than start time. No tape damage resulted from scanning the stationary tape for the 15 second stop intervals but during two intervals, one of the video heads gunked. In both instances the head (and output signal) cleaned up with 5 seconds after the record cycle was resumed. This gunking, of course, would not have occurred with a tape lift mechanism.

6.4 DIGITAL APPLICATIONS

Digital recording can be performed by the recorder in several different ways. In the standard television configuration, a digital signal could be recorded and reproduced directly through the FM electronics at bit rates approaching the system bandwidth. In this mode, however, the switching transients (see Para 3.10.1.3) which occur twice for each headwheel revolution, could significantly influence the accuracy. A more desirable implementation would employ diphase, biphase or split phase encoding and operate directly through the record amplifier. Elimination of the switching transient can be reliably accomplished with this recording scheme if the bit rates are restricted to 250 kilobits/sec at the 0.5 MHz bandwidth mode and 2.0 megabits/sec in the 4.0 MHz bandwidth mode.

The key to elimination of the switching transients is operation at recorded wavelengths which are sufficiently long to allow coherent addition of the outputs of the two video heads, a recombining arrangement which can be used instead of the 2 x 1 switch (see para. 3.6). Reliable additive combination of signals requires that the length of the recorded scan lines repeat from record to playback with a tolerance of less than 90 degrees of the shortest recorded wavelengths. In the course of the development program, the additive combination of signals was evaluated at the wavelengths associated with the present FM system and at frequencies of approximately half the system bandwidths. At the normal FM frequencies the head outputs added coherently most of the time (estimate: 98-99%). At frequencies around half the system bandwidths the signals consistently added coherently. Accuracy tests were attempted on the latter scheme but servo problems developed and necessitated a termination of the tests.

Accuracies of 1 in 10^5 to 1 in 10^6 have been attained previously in scan type recorders and should be feasible in this equipment, especially at the relatively longer wavelengths required for the additive switch. Finally, if a diphase, biphase or split phase signal is not available in a system, the FM modulator and demodulator could be replaced by NRZ to diphase encoders/decoders so that the recorder could directly accept and return any NRZ format. The basic recording in this arrangement would still be of the diphase type so that all the advantages inherent in this recording scheme would still apply.

6.5 COLOR RECORDING

Prior to Pre-Acceptance testing of the recorder, an evaluation was made of the unit's ability to record and reproduce standard NTSC color signals. The evaluation was made with the normal record/reproduce sequence but with the output signal processed through a heterodyne color processor equivalent to that used on the early broadcast recorders. This processor is essential since the basic time stability of the recorder is inadequate for direct color recording with the NTSC standards.

The tests demonstrated that the recorder, with the processor, had the basic potential for good color operation since a "reasonable" picture quality was obtained. Deficiencies in the presentation, however, indicated that refinements would be necessary in several areas.

First the hunting of the unservo'ed headwheel was occasionally severe enough that a hue shift resulted in the picture. This effect could be eliminated in several ways; directly, by damping the motor either mechanically or electronically, or indirectly, in a two recorder system, by compensating for the time base errors derived from the space recorder with a servo in the ground recorder. If a ground recorder is planned for any system, the compensation should be performed at that site, first because the basic capability exists in most ground equipment, and second, because the space recorder can be maintained in its simplest form.

A second performance characteristic which yielded a picture degradation appeared to involve the switching transients. In the normal black and white operation these transients had the appearance of a signal drop-out with a duration of about 1 μsec. In the color system however about 3-4 lines were normally garbled in the area of the switching transients. The exact reason for this extended effect is not known at this time but, in any event, it should be eliminated by synchronous switching and blanking as in the standard broadcast machines.

The final area of refinement for good color quality relates to the distortion introduced by the signal processing electronics in the recorder. When a live color program was recorded and reproduced, the distortion products were not readily apparent, but reproduction of color bars contained an obvious beat pattern. This beat pattern was due to intermodulation distortion which could be significantly reduced with more complex equalization circuitry and FM standards which are optimum for color rather than black and white S/N.

APPENDIX A

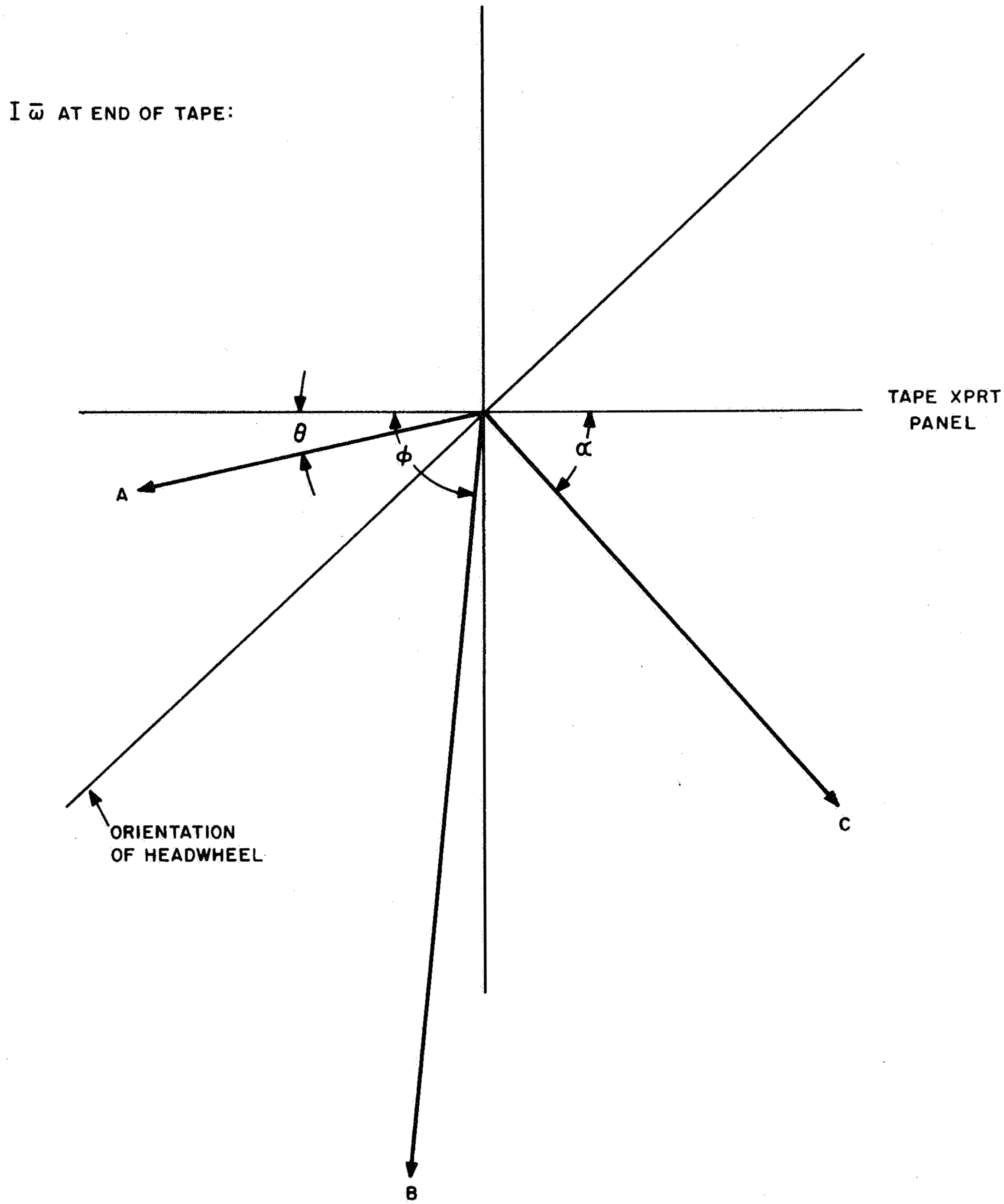
ANGULAR MOMENTUM CALCULATIONS

Although there was no contractual requirement, calculations were made of the residual angular momentum of the recorder during various operating modes. From these values, the average torque imparted to the mounting structure during a change in operating mode can be determined knowing the time required to complete a particular change.

The maximum angular momentum of 0.876 lb-in.-sec. directed toward the mounting surface at an inclination of 87.2° to the surface occurs during the beginning of the rewind mode. ("B" of Figure A-1.) This could be reduced to 0.588 lb-in.-sec. at 52.8° by running the headwheel assembly in a reverse direction at high speed during rewind.

Figure A-2 shows a plot of the calculated angular momentum of the reeling system as a function of tape pack from beginning to end of tape. Both "rewind" and "high-run" modes are shown.

The results of the calculations are listed in Table A-1.



A, HIGH RUN, 0.385 LB_F IN. SEC, $\theta = 22.8°$

B, REWIND, 0.876 LB_F IN. SEC, $\phi = 87.2°$

C, MODIFIED REWIND, 0.588 LB_F IN. SEC, $\alpha = 52.8°$

Figure A-1. Angular Momentum in Various Modes

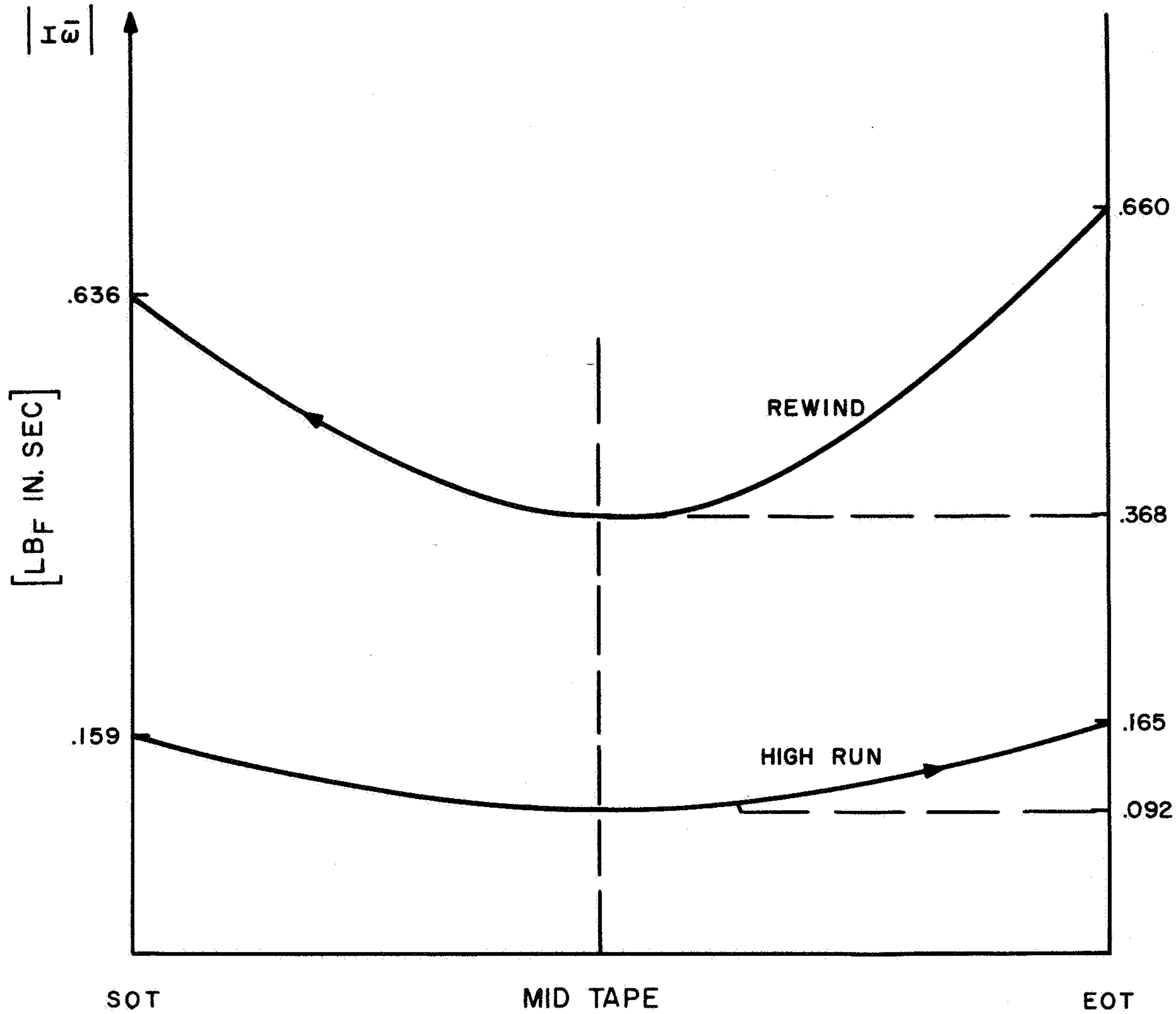


Figure A-2. Angular Momentum of Reeling System

TABLE A-1. ANGULAR MOMENTUM TABULATIONS

		(10 ips)	(1.25 ips)	(40 ips)	High Run	Low Run	Rewind
	Io (x 10^3) lb-in-sec^2	$\bar{\omega}$ High Run 1/sec.	$\bar{\omega}$ Low Run 1/sec.	$\bar{\omega}$ Rewind 1/sec.	$\bar{\omega}$ (x 10^3) lb-in-sec	$\bar{\omega}$ (x 10^3) lb-in-sec	$\bar{\omega}$ (x 10^3) lb-in-sec
Top Reel @ EOT	15.4	+ 2.99†	+.374	-11.95	+ 46.1	+ 5.8	-184
Bottom Reel @ EOT	51.4	+ 2.32	+.290	- 9.28	+119	+14.9	-476
Headwheel Motor	79.6 (10^{-3})	-800π*	-100π*	-100π*	-200*	-25.0*	- 25.0*
Headwheel	100 (10^{-3})	-960π*	-120π*	-120π*	-302*	-37.8*	- 37.8*
Capstan	175 (10^{-3})	+ 20	+2.5	- 80	+ 3.5	+ .4	- 14.0
Idler	55.3 (10^{-3})	+112	+14	-448	+ 6.2	+ .8	- 24.8
Capstan Motor	51.9 (10^{-3})	$+200\pi$	$+25\pi$	-800π	+ 32.6	+ 4.1	-130.4
Rollers	38.5 (10^{-3})	- 32	-4	+128	- 1.2	- .05	+ 4.8

*Inclined @ 45° to tape transport

†From reel side, CCW taken as positive

APPENDIX B

BELT LIFE CALCULATIONS

t = thickness of belt

M = torque transfer necessary

T_o = initial tension

r = smaller radius

θ = smaller wrap angle (radians)

μ = coeff. of friction, .20

$$M = 2\, T_o\, r \left[\frac{e^{\mu\theta} - 1}{e^{\mu\theta} + 1}\right]$$

$$T_o = \frac{M}{2\,r}\left[\frac{e^{\mu\theta} + 1}{e^{\mu\theta} - 1}\right]$$

Headwheel Belt:

$$T_o = \frac{1.2}{2\,(.5)}\left[\frac{1.84 + 1}{1.84 - 1}\right] = 3.38 \text{ oz.}$$

Initial Stress,

$$s_i = \frac{3.38\,(10^3}{16\,(.5)} = 412 \text{ psi}$$

Flexure Stress,

$$s_f = \frac{E\,t}{2r} = \frac{550\,(10^3)\,(2)\,(10^{-3})}{1.0}$$

$$s_f = 1100 \text{ psi, peak-to-peak}$$

Average Stress,

$$s_w = 412 + .5\,(1100) = 965 \text{ psi}$$

Centrifugal Effect on HW belt:

J, belt velocity $= 1506$ ips

mylar density, $\gamma = .05 \text{ lb/in}^3$

Centrifugal Stress,

$$S_g = \frac{\gamma \overline{V}^2}{g} = \frac{.05}{386} (2.26)\, 10^6$$

$$S_g = 293 \text{ psi}$$

Change S_o to $S_o' = 293 + 412 = 705$ psi

Change T_o to $T_o' = 4.38$ oz.

Change S_{AV} to $S_{AV} = 705 + 550 = 1255$ psi

Motor to idler Belt:

$$T_o = \frac{.4}{.25} \left[\frac{2.361}{.361}\right] = 10.5 \text{ oz.}$$

$$S_o = \left(\frac{10.5}{16}\right) \left(\frac{10^3}{.375}\right) = 1750 \text{ psi}$$

$$S_f = \frac{550\,(10^3)\,(1.5)\,(10^{-3})}{.25} = 3.3\,(10^3) \text{ psi}$$

(Peak to Peak)

$$S_{AV} = 1750 + .5\,(3300) = 3400 \text{ psi}$$

Idler to Capstan Belt:

$$\mu = .4 \left(\frac{1.4}{.25}\right) = 2.24 \text{ in. oz.}$$

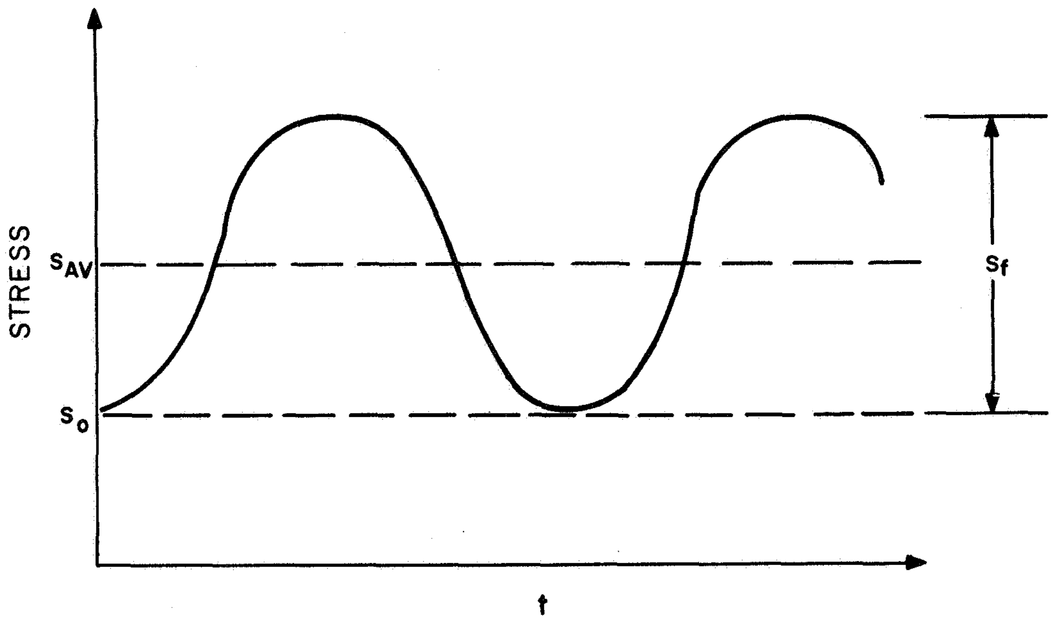
$$T_o = 6.55 \left(\frac{2.24}{.25}\right) = 58.5 \text{ oz.} = 3.68 \text{ lb}$$

Initial Stress,

$$S_o = \frac{3.68\,(10^3)}{.352} = 1.05\,(10^4)\ \text{psi}$$

$$S_f = 3.3\,(10^3)\ \text{psi (peak to peak)}$$

$$S_{AV} = 10.5\,(10^3) + .5\,(3.3 \times 10^3) = 12.2\,(10^3)\ \text{psi}$$



A conventional technique for predicting the fatigue life of metallic members under combined steady and fluctuating stresses is a graphical construction known as the Goodman Diagram. Useful adaptation of this technique has been made to the design of Mylar belts. In Figure B-1, a Goodman Diagram has been plotted for indefinite life using the Light-White belt failure data. It was found that the headwheel and capstan motor belts have an indefinite theoretical life. The idler to capstan belt is shown to have a finite life. This point was plotted with values obtained with a 1.5 mil belt thickness. This belt thickness was later increased to 2 mils to achieve theoretical indefinite life.

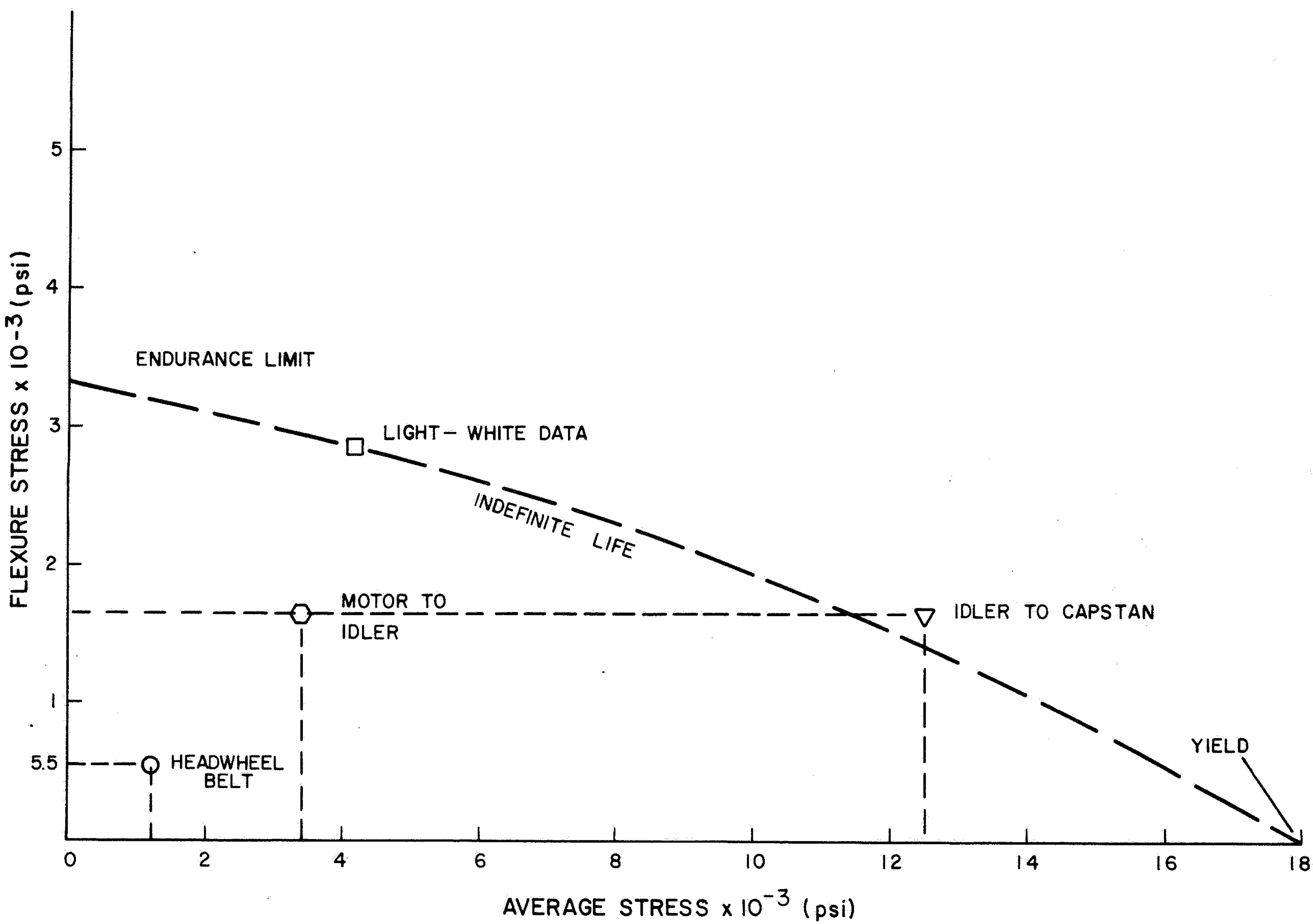


Figure B-1. Goodman Diagram, Belt Life

TABLE B-1. SUMMARY OF BELT PARAMETERS

Belt Information	Motor to Idler	Idler to Capstan	Headwheel
Diameter (in.)	2.059	2.214	2.676
Width (in.)	.250	.250	.250
Thickness (in.)	.0015	.0015	.002
Pulley Wrap (radians)	3.44, 2.84	3.42, 2.86	3.22, 3.06
Cross-section (in.^{2})	.375 (10^{-3})	.352 (10^{-3})	.50 (10^{-3})
*Torque Transfer (in. oz.)	.4	2.24	1.2
Initial Stress, S_o (psi)	1750	10500	705 ♦
† Flexure Stress, S_f (psi)	3300	3300	1100
Average Stress, S_{AV} (psi)	3400	12200	1255 ♦
‡ Belt Speed (fpm)	392	70	7540
‡ Belt Cycles (cycles/min.)	728	121	10800
Theoretical Life	∞	∞	∞

*@smaller pulley
† peak to peak, the range stress used in the Goodman diagram is one half this amount
‡ in high forward mode
♦ with compensation for centrifugal effect

APPENDIX C

FAILURE ANALYSIS MEMO

INTERNAL CORRESPONDENCE

DATE April 13, 1967

TO C. M. Russell LOCATION 10-5

FROM A. Siegel, PC 3915 LOCATION 1-6-5

SUBJECT Analysis of Two (2) TO-5 Size Relays Manufactured by Teledyne.

The two subject relays were received and visually examined. One (Model No. 412) was a DPDT unit while the second (Model No. 411) had a SPOT contact configuration. The lot codes on both relays indicated that they had been manufactured many months ago; the exact date cannot be determined without an inquiry to the manufacturer. We do know that during October of 1966, this manufacturer changed his cleaning process to remove particle contamination from within the contact chamber. At approximately this same time, the supplier found that the sealing of the cover of the relay to the header sometimes caused misadjustment when the cover applied a force to the relay frame. The manufacturer therefore, added a procedure which would seat the cover and determine whether this interference could take place. This removed the problem which manifested itself in a lack of overtravel in the relay. Both relays being examined were manufactured prior to the implementation of these two procedures.

Examining the Model 412 unit electrically revealed no problems. Contact Voltage Drop readings for both sets of contacts revealed readings within normally expected levels. There is a possibility that minute particles of dirt had lodged themselves in the contacts causing difficulties in your equipment, but the normal handling during removal from equipment and transportation to my desk could have jarred them loose so that they presently do not affect relay operation. Opening of the relay did not reveal their presence.

This second relay (Model 411) indicated an open NO contact with the relay energized. After carefully opening the unit and microscopically examining the contacts, it was determined that the relay exhibited marginal closure of the NO contact with no overtravel; one of the results of the cover to frame interference problem.

It is recommended that the manufacturer be contacted and the effectivity lot code of the changes in production techniques (previously discussed) determined. Any relays containing lot codes indicating manufacture prior to that date should not be used.

A. Siegel (Signed)
Electromechanical Parts Group
Central Engineering

AS:jc
ENCL: Data Sheet
2 Relays
xc: B. R. Schwartz

RCA 32 (3-62)